The City of San Diego

Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall 2009

City of San Diego
Ocean Monitoring Program

Public Utilities Department
Environmental Monitoring and Technical Services Division

THE CITY OF SAN DIEGO

June 30, 2010

Mr. David Gibson, Executive Officer
Regional Water Quality Control Board
San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Attention: POTW Compliance Unit

Dear Sir:

Enclosed is the 2009 Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall as required per NPDES Permit No. CA0107409, Order No. R9-2002-0025. This report contains data summaries, analyses and interpretations of the various portions of the ocean monitoring program, including oceanographic conditions, water quality, sediment characteristics, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Sincerely,

Steve Meyer
Deputy Public Utilities Director

SM/tds

Enclosures: 1. Annual Receiving Waters Monitoring Report
2. CD containing PDF file of this report

cc: Department of Environmental Health, County of San Diego
U.S. Environmental Protection Agency, Region 9
Public Utilities Department Library, City of San Diego

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for the
Point Loma Ocean Outfall

2009

Prepared by:

City of San Diego
Ocean Monitoring Program
Public Utilities Department
Environmental Monitoring and Technical Services Division

June 2009

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Cover Photo

View of the ocean and seacliffs from the Point Loma Wastewater Treatment Plant. Photo by Andrew Davenport.

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Executive Summary

Executive Summary

The City of San Diego (City) conducts extensive ocean monitoring to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the Point Loma Ocean Outfall (PLOO). The data collected are used to determine compliance with receiving water conditions as specified in the National Pollution Discharge Elimination System (NPDES) permit for the City's Point Loma Wastewater Treatment Plant (PLWTP).

The primary objectives of the Point Loma ocean monitoring program are to a) measure compliance with NPDES permit requirements and 2001 California Ocean Plan (Ocean Plan) standards, and b) assess any impact of wastewater discharged through the outfall on the local marine environment, including effects on water quality, sediment conditions, and marine organisms. The study area encompasses approximately 184 km^2 of coastal waters centered around the PLOO discharge site, which is located approximately 7.2 km offshore of the PLWTP at a depth of nearly 100 m. Shoreline monitoring extends from Mission Beach southward to the tip of Point Loma, while regular offshore monitoring occurs in an adjacent area at sites ranging from about 9 to 116 m in depth.

The City conducts other types of studies in addition to its regular monitoring for Point Loma that are useful for evaluating patterns and trends over time or that span broader geographic regions, thus providing additional information to help distinguish reference areas from sites that may be affected by anthropogenic influences. For example, prior to the initiation of wastewater discharge at the present deepwater location in late 1993, the City conducted a 2½-year baseline study designed to characterize background environmental conditions in the Point Loma region. Additionally, a broader geographic survey of benthic conditions is typically conducted during the summer each year at sites ranging from northern San Diego County (around La Jolla–Del Mar) south to the U.S./Mexico international border as part of the monitoring program for the South Bay Ocean Outfall. Results of the 2009 regional survey are included in the annual receiving waters monitoring report for the South Bay outfall region. The City also collaborates with other organizations on larger-scale, regional monitoring projects that span the entire Southern California Bight (SCB). These bight-wide surveys include the original pilot project in 1994, and subsequent Bight'98, Bight'03, and Bight'08 projects (see Chapter 1).

The receiving waters monitoring activities for the Point Loma region are separated into several major components, which are organized into seven chapters in this report. Chapter 1 presents a general introduction and overview of the Point Loma ocean monitoring program, as well as background information on wastewater treatment processes at the PLWTP, including the initiation of chlorination in late 2008. In Chapter 2, data regarding various physical and chemical parameters are evaluated to characterize oceanographic conditions and water mass transport potential for the region. Chapter 3 presents the results of water quality monitoring conducted along the shore and in local coastal waters, including measurements of fecal indicator bacteria (FIB) to determine compliance with Ocean Plan water-contact standards. Assessments of benthic sediment quality and the status of soft-bottom macrobenthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of demersal (bottom dwelling) fishes and megabenthic invertebrates. Bioaccumulation assessments to determine if contaminants are present in the tissues of local fishes captured via trawls or by hook and line are presented in Chapter 7. In addition to the above activities, the City supports other projects relevant to assessing the quality of ocean waters in the region. One such project involves aerial and satellite imaging studies of the San Diego/Tijuana coastal regions. The results of these remote sensing efforts conducted during 2009 are incorporated herein into discussions and interpretations of oceanographic and water quality conditions (see Chapters 2 and 3).

This report focuses on the results and conclusions of all ocean monitoring activities conducted in the Point Loma region from January 2009 through December 2009. An overview and summary of the main findings for each of the major components of the program are included below.

Oceanographic Conditions

The Point Loma outfall region was characterized by relatively normal oceanographic conditions in 2009 that were typical of previous years. This included seasonal patterns such as coastal upwelling with corresponding phytoplankton blooms in the spring, maximum stratification (layering) of the water column in mid-summer, and reduced stratification during the winter and fall. Although some differences in salinity, dissolved oxygen, pH, and transmissivity were observed close to the discharge site, it was also clear that variation among stations was small and restricted to a highly localized area around the outfall. Remote sensing observations revealed no evidence of the wastewater plume reaching near-surface waters, even during the winter and fall when the water column was only weakly stratified. This is consistent with results from the bacteriological surveys (see below). Overall, the observed variations in ocean conditions in 2009 were consistent with expectations due to typical seasonal cycles, as well as with changes in larger patterns reported for the California Current System. Together, this suggests that other factors such as the upwelling of cool, nutrient-rich deep waters during the spring months, the occurrence of associated plankton blooms, and the effects of large-scale oceanographic events may best explain most of the temporal and spatial variability observed in the region.

Water Quality

There was no evidence that wastewater discharged to the ocean via the PLOO reached surface or near-shore recreational waters in 2009. For example, the wastewater plume was not detected in any aerial or satellite imagery taken during the year. Although elevated counts for fecal indicator bacteria (FIB) such as total coliforms, fecal coliforms and/or enterococcus were occasionally detected along the shore and at a few nearshore stations, concentrations of these bacteria tended to be relatively low overall. In general, elevated FIB densities were limited to instances when contamination was most likely associated with rainfall (i.e., storms), wildlife, heavy recreational use, or decaying plant material (e.g., kelp and seagrass). The elevated FIB counts that could likely be attributable to wastewater discharge were limited to offshore waters at depths of 60 m or below. This finding supports previous water quality analyses for the region, which have indicated that the PLOO wastefield typically remains offshore and submerged in deep waters.

Compliance with the 2001 California Ocean Plan water contact standards was very high in 2009. For example, all of the kelp stations and six of the eight shore stations off Point Loma were in complete compliance with all four of the Ocean Plan standards throughout the year. The few exceedances that occurred during the year at shore stations D8 and D11 generally reflected trends in elevated bacterial levels between the months of January–March and in December when rainfall was greatest.

Sediment Conditions

Ocean sediments at stations surrounding the PLOO in 2009 were comprised primarily of fine sands and coarse silt, which is similar to patterns seen in previous years. Differences in the particle size composition of Point Loma sediments are likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geological origins of different sediment types, and recent deposits of detrital materials. There was no evident relationship between sediment composition and proximity to the outfall discharge site.

Overall, sediment quality at the PLOO monitoring sites was similar in 2009 to previous years, and there were few clear patterns in contaminant accumulation relative to the discharge site. The only exceptions were slightly elevated sulfide and

BOD levels at a few stations located within about 300 m of the outfall. Sediment concentrations of the various trace meals, organic loading indicators, pesticides (e.g., DDT), PCBs and PAHs remained within the typical range of variability for San Diego and other coastal areas of southern California. The potential for degradation by any of the detected chemical contaminants was further evaluated by using the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines as benchmarks. None of the contaminants detected in 2009 exceeded either their ERL or ERM. Additionally, the highest concentrations of several contaminants occurred at sites relatively distant from the outfall. For example, concentrations of several organic indicators and metals were highest in sediments from the northern-most stations. In contrast, several pesticides, PCBs, and PAHs were detected mostly in sediments from stations located south of the outfall. This latter pattern is consistent with other studies that have suggested that sediment contamination at these and other southern stations off San Diego is most likely due to misplaced deposits (short dumps) of sediments originally destined for the LA-5 dredged materials disposal site.

Macrobenthic Communities

Benthic macrofaunal communities surrounding the PLOO in 2009 were dominated by ophiuroid-polychaete based assemblages, with few major changes having occurred since monitoring began in 1991. Polychaete worms and ophiuroids (brittle stars) were the most abundant and diverse taxa in the region. Although many of the assemblages present during the year were dominated by similar species, the relative abundance of these species varied among sites. The brittle star *Amphiodia urtica* was the most abundant and widespread species in the region, while the bivalve *Axinopsida serricata* was the second most widespread benthic invertebrate. Overall, these assemblages were typical of those occurring in other mid-depth areas of the SCB with similar, relatively fine sediment habitats.

Benthic conditions off Point Loma did reflect some changes in 2009 that may be expected near large ocean outfalls, although these effects were restricted to a relatively small, localized region within about 300 m of the outfall diffuser legs. For example, some descriptors of benthic community structure (e.g., infaunal abundance, species diversity) or populations of indicator species (e.g., *A. urtica*) have shown small changes over time between reference areas and sites located nearest the outfall. However, results for the benthic response index (BRI) were characteristic of undisturbed sediments. In addition, changes in macrofaunal community structure that did occur during the year were similar in magnitude to those that have occurred previously and elsewhere off southern California. Overall, macrofaunal assemblages in the region remain similar to those observed prior to wastewater discharge and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf. There was no evidence that wastewater discharge has caused degradation of the marine benthos in the PLOO monitoring region.

Demersal Fishes and Megabenthic Invertebrates

Pacific sanddabs continued to dominate fish assemblages surrounding the PLOO during 2009 as they have for many years. This species occurred at all stations and accounted for 50% of the total fish catch. Other characteristic, but less abundant fish included halfbanded rockfish, Dover sole, longspine combfish, shortspine combfish, plainfin midshipman, California lizardfish, English sole, and pink seaperch. Although the overall composition and structure of the local fish assemblages varied among stations, most differences were due to fluctuations in Pacific sanddab populations.

Assemblages of relatively large (megabenthic) trawl-caught invertebrates in the region were similarly dominated by a single species, the white sea urchin *Lytechinus pictus*. Consequently, variations in megabenthic community structure off Point Loma generally reflect changes in the abundance of this urchin, as well as other common species such as the sea pen *Acanthoptilum* sp, the sea stars *Astropecten verrilli* and *Luidia foliolata*, the sea cucumber *Parastichopus californicus*, and the brittle star *Ophiura luetkenii*.

Overall, the 2009 trawl survey results indicate that trawl-caught fish and invertebrate communities in the region are unaffected by wastewater discharge. Although highly variable, patterns in the abundance and distribution of these organisms were similar at stations located near the outfall and farther away, suggesting a lack of significant anthropogenic influence. Instead, changes in these communities appear to be more likely due to natural factors such as seasonal water temperature fluctuations or large-scale oceanographic events (e.g., El Niño), as well as the mobile nature of many species.

The types and frequencies of external health problems for fish can be important indicators of environmental impact. Examinations of trawl-caught fish for evidence of disease (e.g., tumors, fin erosion, skin lesions) or the presence of ectoparasites showed that local fish populations remain healthy. For example, external parasites and other external abnormalities occurred in less than 2% of the fish collected in the Point Loma region during 2009. Overall, these results were consistent with findings from previous years and provided no indication of outfall effects.

Contaminants in Fish Tissues

There was no clear evidence to suggest that tissue contaminant loads in fish captured at the PLOO monitoring sites were affected by the discharge of wastewater in 2009. Although several metals, two pesticides, and various PCB congeners were detected in liver tissues from flatfish and muscle tissues from rockfish sampled in the region, these contaminants were found in fishes distributed widely among stations and showed no patterns that could be attributed to wastewater discharge. Further, all contaminant values were within the range of those reported previously for southern California fishes. Finally, while some muscle tissue samples from sport fish collected off Point Loma had arsenic and selenium concentrations above the median international standard for shellfish, and some samples had mercury and PCB levels that exceeded OEHHA fish contaminant goals, concentrations of mercury and DDT were still below U.S. FDA human consumption limits.

The occurrence of both trace metals and chlorinated hydrocarbons in the tissues of Point Loma fishes may be due to many factors, including the widespread distribution of many contaminants in coastal sediments off southern California. Other factors that affect the bioaccumulation and distribution of contaminants in local fishes include the different physiologies and life history traits of various species. Exposure to contaminants can vary greatly between species and even among individuals of the same species depending on migration habits. For example, fish may be exposed to pollutants in a highly contaminated area and then move into a region that is less contaminated. This is of particular concern for fishes collected in the vicinity of the PLOO, as there are many other point and non-point sources in the region that may contribute to contamination.

Conclusions

The findings and conclusions for the 2009 ocean monitoring effort for the Point Loma outfall region were consistent with previous years. Overall, there were limited impacts to local receiving waters, benthic sediments, and marine invertebrate and fish communities. There was no evidence that the PLOO wastefield reached surface waters or nearshore recreational areas during the year. Although elevated bacterial levels did occur along the shore and at various kelp bed sites, such instances were largely associated with higher rainfall during the wet season and not to shoreward transport of the wastewater plume. There were also no outfall related patterns in sediment contaminant distributions, or in differences between the various macrobenthic invertebrate and fish assemblages. The general lack of disease symptoms in local fish populations, as well as the low level of contaminants detected in fish tissues, was also indicative of a healthy marine environment. Finally, benthic habitats in the region remain in good condition similar to much of the Southern California Bight mainland shelf.

Chapter 1
General Introduction

Chapter 1. General Introduction

INTRODUCTION

Treated effluent from the City of San Diego's Point Loma Wastewater Treatment Plant (PLWTP) is discharged to the Pacific Ocean through the Point Loma Ocean Outfall (PLOO) according to requirements set forth in National Pollutant Discharge Elimination System (NPDES) Permit No. CA0107409, Order No. R9-2002-0025. This Order and associated Monitoring and Reporting Program (MRP) were adopted by the Regional Water Quality Control Board (RWQCB), San Diego Region, on April 10, 2002. During 2003, the MRP requirements for the Point Loma region were modified with adoption of Addendum No. 1 to the above Order (see City of San Diego 2004), which became effective August 1, 2003. The Order was further modified on August 13, 2008 by the adoption of Addendum No. 2, which gave the City approval to initiate operation of a prototype disinfection system at the PLWTP.

The MRP for Point Loma defines the requirements for ambient receiving waters monitoring in the region off Point Loma, including the overall sampling design, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines. The main objectives of the ocean monitoring program are to provide data that satisfy the requirements of the NPDES permit, demonstrate compliance with provisions of the 2001 California Ocean Plan (COP), detect movement and dispersion of the waste field in local coastal waters, and identify any biological or chemical changes that may be associated with wastewater discharge.

Background

The City of San Diego (City) began operation of the PLWTP and original ocean outfall off Point Loma in 1963, at which time wastewater was discharged approximately 3.9 km offshore at a depth of about 60 m. From 1963 to 1985, the plant operated as a primary treatment facility, removing approximately 60% of the total suspended solids (TSS) by gravity separation. Since then, considerable improvements have been made to the treatment process. The City began upgrading the process to advanced primary treatment (APT) in mid-1985, with full APT status being achieved by July of 1986. This improvement involved the addition of chemical coagulation to the treatment process, and resulted in an increased TSS removal of about 75%. Since 1986, treatment has been further enhanced with the addition of several more sedimentation basins, expanded aerated grit removal, and refinements in chemical treatment. These enhancements have resulted in lower mass emissions from the plant. TSS removals are now consistently greater than the 80% permit requirement. Finally, the City began testing disinfection of PLWTP effluent using a sodium hypochlorite solution in September 2008 following adoption of Addendum No. 2 to Order No. R9-2002-0025 (see above). These chlorination activities continued throughout 2009.

Additional changes occurred in the early 1990s when the PLOO was extended approximately 3.3 km further offshore in order to prevent intrusion of the wastewater plume into nearshore waters and to increase compliance with standards set forth in the COP for water-contact sports areas. Construction of the outfall extension was completed in November 1993, at which time discharge was terminated at the original 60 m site. The outfall presently extends approximately 7.2 km offshore to a depth of about 94 m, where the pipeline splits into a Y-shaped multiport diffuser system. The two diffuser legs extend an additional 762 m to the north and south, each terminating at a depth of about 98 m.

The average daily flow of effluent through the PLOO in 2009 was 153 mgd, ranging from a low of 133 mgd in November to a high of about 210 mgd the previous February. Overall, this represents about a 6% decrease from the average flow rate of 162 mgd in 2008. TSS removal averaged about 90% during 2009, with a total mass emissions of approximately 6774 mt/yr relative to 7169 mt/yr in 2008 (see City of San Diego 2010a).

Receiving Waters Monitoring

Prior to 1994, the City conducted an extensive ocean monitoring program off Point Loma surrounding the original 60-m discharge site. This program was subsequently modified and expanded with the construction and operation of the deeper outfall. Data from the last year of regular monitoring near the original inshore site are presented in City of San Diego (1995a), while the results of a 3-year "recovery study" are summarized in City of San Diego (1998). From 1991 through 1993, the City also conducted a voluntary "pre-discharge" study in the vicinity of the new site in order to collect baseline data prior to the discharge of effluent in these deeper waters (City of San Diego 1995a, b). Results of NPDES mandated monitoring for the extended PLOO from 1994 to 2008 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2009). In addition, the City has conducted annual region-wide surveys off the coast of San Diego since 1994 either as part of regular South Bay monitoring requirements (e.g., see City of San Diego 1999, 2010b) or as part of larger, multi-agency surveys of the entire Southern California Bight. The latter include the 1994 Southern California Bight Pilot Project (e.g., Allen et al. 1998, Bergen et al. 1998, 2001; Schiff and Gossett 1998) and subsequent Bight'98 and Bight'03 programs in 1998 and 2003, respectively (e.g., Allen et al. 2002, 2007; Noblet et al. 2003, Ranasinghe et al. 2003, 2007; Schiff et al. 2006), as well as the current Bight'08 regional monitoring survey that began during the summer of 2008 (e.g., Bight'08 CEC 2008). Such large-scale surveys are useful in characterizing the ecological health of diverse coastal areas and may help to identify and distinguish reference sites from those impacted by wastewater or stormwater discharges, urban runoff, or other sources of contamination.

The current sampling area off Point Loma extends from the shoreline seaward to a depth of about 116 m and encompasses an area of approximately 184 km^2 (Figure 1.1). Fixed sites are generally arranged in a grid surrounding the outfall and are monitored in accordance with a prescribed sampling schedule. Results of relevant quality assurance procedures for the receiving waters monitoring activities are included in the EMTS Division Laboratory Quality Assurance Report (City of San Diego 2010c). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the RWQCB and U.S. EPA throughout the year are available online at the City's website (i.e., www.sandiego.gov/mwwd).

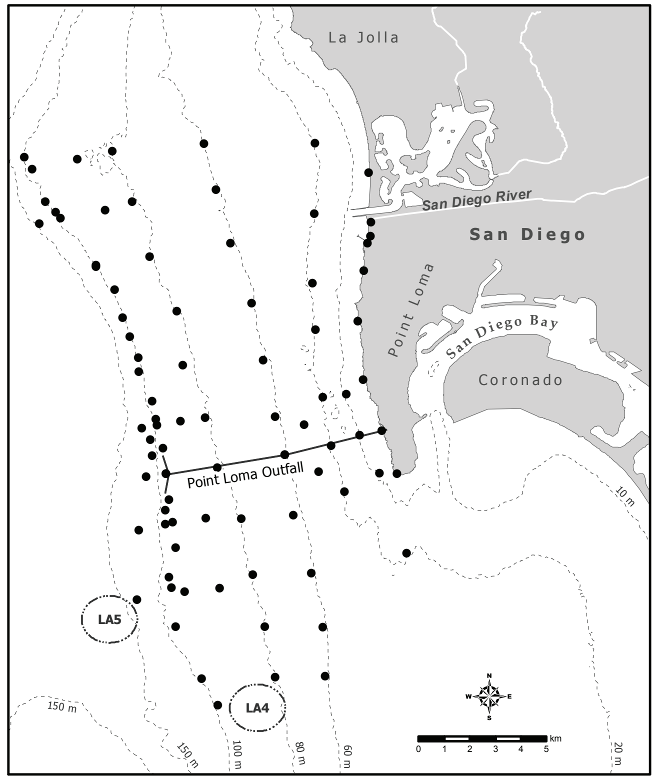

Figure 1.1
Receiving waters monitoring stations for the Point Loma Ocean Outfall Monitoring Program.

In addition to the above activities, the City participates in or supports other projects relevant to assessing ocean quality in the region. One such project involves satellite and aerial monitoring of the San Diego/Tijuana coastal region that is jointly funded by the City and the International Boundary and Water Commission (e.g., Svejkovsky 2010). A long-term study of the Point Loma kelp forest funded by the City is also being conducted by scientists at the Scripps Institution of Oceanography (see City of San Diego 2003), while the City also participates with a number of other agencies to fund aerial surveys of all the major kelp beds from San Diego and Orange Counties (e.g., MBC 2009). Finally, the current MRP includes plans to perform adaptive or special strategic process studies as determined by the City in conjunction with the RWQCB and U.S. EPA. Such studies have included a comprehensive scientific review of the Point Loma ocean monitoring program (SIO 2004), a large-scale sediment mapping study of both the Point Loma and South Bay coastal regions (see Stebbins et al. 2004), and a pilot study of deep benthic habitats of the continental slope off San Diego (see Stebbins and Parnell 2005). Additional work in these deeper habitats is ongoing with a final report expected in late 2010 or early 2011. In 2004 the City also began sampling again at the recovery stations mentioned above as part of a long-term annual assessment project of benthic conditions near the original outfall discharge site. In addition, a multi-phase project is currently underway to examine the dynamics and strength of the thermocline and local currents of the receiving waters off Point Loma as well as the dispersion behavior of the PLOO wastewater plume (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010).

This report presents the results of all regular receiving waters monitoring activities conducted as part of the Point Loma ocean monitoring program in 2009. However, in order for the City to participate in the Bight'08 regional monitoring program, a resource exchange agreement was approved by the RWQCB that relaxed some regular monitoring requirements for both the Point Loma and South Bay regions. The relevant changes for 2009 included: (1) benthic sampling off Point Loma during January was reduced from 22 stations to the 12 "primary core" stations located along the 98-m depth contour; (2) trawl sampling off Point Loma during January was reduced from six stations to just the two trawl stations located nearest the outfall. The major components of the monitoring program are covered in the following chapters: Oceanographic Conditions, Water Quality, Sediment Characteristics, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, and Bioaccumulation of Contaminants in Fish Tissues. A glossary of technical terms is included.

Literature Cited

Allen, M.J., S.L. Moore, K.C. Schiff, S.B. Weisberg, D. Diener, J.K. Stull, A. Groce, J. Mubarak, C.L. Tang, and R. Gartman. (1998). Southern California Bight 1994 Pilot Project: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J., T. Mikel, D. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S. Walther, G. Deets, C. Cash, S. Watts, D.J. Pondella II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce, and J.L. Armstrong. (2007). Southern California Bight 2003 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Costa Mesa, CA.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

[Bight'08 CEC] Bight'08 Coastal Ecology Committee. (2008). Southern California Bight Regional Marine Monitoring Survey (Bight'08) Coastal Ecology Workplan. Southern California Coastal Water Research Project, Costa Mesa, CA. [available at www.sccwrp.org]

City of San Diego. (1995a). Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 1994. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1995b). Outfall Extension Pre-Construction Monitoring Report (July 1991–October 1992). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1998). Recovery Stations Monitoring Report for the Original Point Loma Ocean Outfall (1991–1996). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2002. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010a). 2009 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010c). EMTS Division Laboratory Quality Assurance Report, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Dayton, P., P.E. Parnell, L.L. Rasmussen, E.J. Terrill, and T.D. Stebbins. (2009). Point Loma Ocean Outfall Plume Behavior Study, Scope of Work. Scripps Institution of Oceanography, La Jolla, CA, and City of San Diego, Metropolitan Wastewater Department, San Diego, CA. [NOAA Award No. NA08NOS4730441]

[MBC] MBC Applied Environmental Services. (2009). Status of the Kelp Beds 2008, San Diego and Orange Counties, Region Nine

Kelp Survey Consortium. Final Report, June 2009. MBC Applied Environmental Services, Costa Mesa, CA.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parnell, E. and L. Rasmussen. (2010). Summary of PLOO hydrographic observations (2006–2009). Draft report to City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

[SIO] Scripps Institution of Oceanography. (2004). Point Loma Outfall Project, Final Report, September 2004. Scripps Institution of Oceanography, University of California, La Jolla, CA.

Stebbins, T.D. and P.E. Parnell. (2005). San Diego Deep Benthic Pilot Study: Workplan for Pilot Study of Deep Water Benthic Conditions off Point Loma, San Diego, California. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Scripps Institution of Oceanography, La Jolla, CA.

Stebbins, T.D., K.C. Schiff, and K. Ritter. (2004). San Diego Sediment Mapping Study: Workplan for Generating Scientifically Defensible Maps of Sediment Conditions in the San Diego Region. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Southern California Coastal Water Research Project, Westminster, CA.

Storms, W.E., T.D. Stebbins, and P.E. Parnell. (2006). San Diego Moored Observation System Pilot Study Workplan for Pilot Study of Thermocline and Current Structure off Point Loma, San Diego, California. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Scripps Institution of Oceanography, La Jolla, CA.

Svejkovsky, J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region. Annual Summary Report, 1 January, 2009 – 31 December 2009. Ocean Imaging, Solana Beach, CA.

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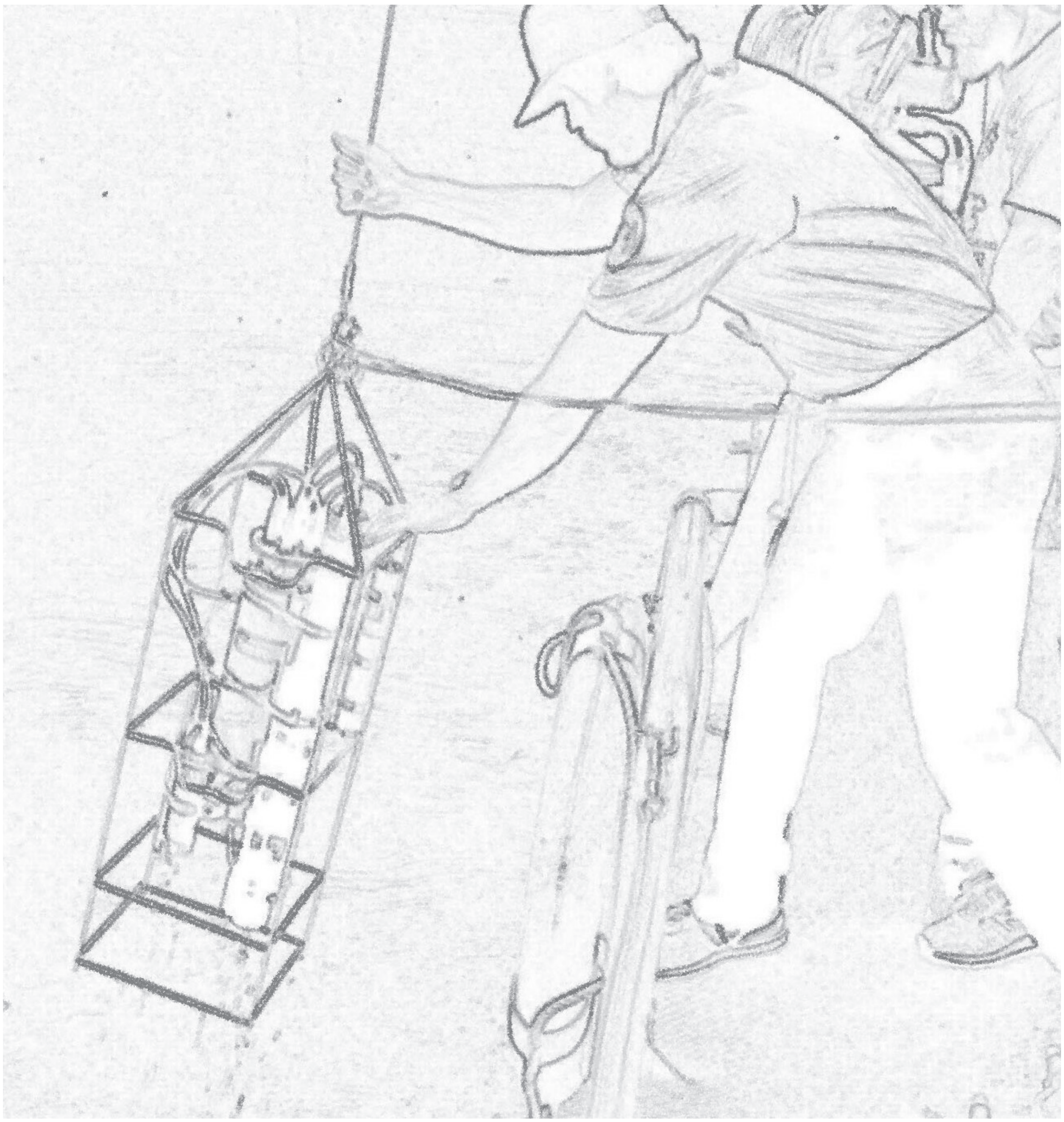
Chapter 2
Oceanographic Conditions



Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the Point Loma Ocean Outfall (PLOO) to assist in evaluating possible impacts of wastewater discharge on the marine environment. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen and pH, in conjunction with biological indicators such as chlorophyll concentrations, are important indicators of biological and physical oceanographic processes (Skirrow 1975) that can impact marine life within a region (Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and the rate of discharge, but also by oceanographic factors that govern water mass movement (e.g., horizontal and vertical mixing of the water column, current patterns), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping.

In relatively nearshore waters such as the PLOO monitoring region, oceanographic conditions are strongly influenced by seasonal changes (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Southern California weather can generally be classified into a wet, winter season (typically December through February) and a dry, summer season (typically July through September) (NOAA/NWS 2010), and differences between these seasons affect oceanographic conditions such as water column stratification and current patterns. For example, storm activity during southern California winters brings higher winds, rain, and waves which often contribute to the formation of a well-mixed, relatively homogenous or non-stratified water column (Jackson 1986). The chance that wastewater plumes from sources such as the PLOO may surface is highest during such times when the water column is well mixed and there is little, if any, stratification. These conditions often extend into spring as the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the increasing elevation of the sun and longer days begin to warm surface waters resulting in increased surface evaporation (Jackson 1986). Mixing conditions also diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes like the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment, contaminant) plumes. In the Point Loma region these include tidal exchange from San Diego Bay and Mission Bay, outflows from the San Diego River, the Tijuana River and northern San Diego County lagoons and estuaries, storm drains or other water discharges, and surface water runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions both individually and synergistically.

This chapter describes the main oceanographic conditions present in the Point Loma region during 2009. The main objectives are to: (1) describe deviations from expected oceanographic patterns, (2) assess possible influence of the PLOO wastewater discharge relative to other input sources, (3) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations. The results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejkovsky 2010). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the PLOO discharge site. In addition to the above, a multi-phase project is currently underway to examine the dynamics and strength of the thermocline and ocean currents off Point Loma, as well as the dispersion behavior of the PLOO wastewater plume using a combination of current meters (ADCPs), thermistor strings, and automated underwater vehicles (AUVs) (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010). Findings from these ongoing new studies are expected to be included in future reports, but are not included herein. Finally, the oceanographic results reported in this chapter are also referred to in Chapters 3–7 to help explain patterns in the distribution of indicator bacteria in the coastal waters off Point Loma, as well as other changes in the local marine environment.

Materials and Methods

Field Sampling

Oceanographic measurements were taken at a total of 44 fixed sampling sites encompassing an area of ~151 km^2 surrounding the PLOO (Figure 2.1). Thirty-six of these sites (stations F01–F36) are located between about 1.7 and 10.2 km offshore of Point Loma along or adjacent to the 18, 60, 80 and 98-m depth contours. These offshore stations were sampled quarterly during the months of February, May, August and November, with each survey occurring over three days. For sampling and analysis purposes, these 36 stations are grouped as follows: (a) stations F02, F03, F11–F14, F23–F25, and F34–F36 comprise the 12 northern water quality (North WQ) sites; (b) stations F07–F10, F19–F22, and F30–F33 comprise the 12 mid-region water quality (Mid-WQ) sites; (c) stations F01, F04–F06, F15–F18, and F26–F29 comprise the 12 southern water quality (South WQ) sites. All stations within each of these three groups are sampled on a single day during each quarterly survey. In addition to the above "F" stations, oceanographic measurements were also taken at eight stations located within the Point Loma kelp forest. These "Kelp WQ" sites include three stations (C4, C5 and C6) paralleling the 9-m depth contour along the inshore edge of the kelp bed, and five stations (A1, A6, A7, C7 and C8) located along the 18-m depth contour near the outer edge of the kelp bed. Although sampling at these kelp stations is conducted five times per month to meet monitoring requirements for indicator bacteria (see Chapter 3), only data from samples collected within about 1–2 days of the above quarterly stations are analyzed in this chapter. See Appendix A.1 for the specific dates all samples were collected during 2009.

Data for the various oceanographic parameters were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), and dissolved oxygen (DO). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data reduction ensured that physical measurements used in subsequent analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the PLOO region during 2009 also included aerial and satellite image analysis performed by Ocean Imaging of Solana Beach, CA (see Svejkovsky 2010). All usable images for the study area captured during the year by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded from Ocean Imaging's website (Ocean Imaging 2010) for each month, as well as 19 high clarity Landsat Thematic Mapper (TM) images. High resolution aerial images were collected using Ocean Imaging's DMSC-MKII digital multispectral sensor and from a Jenoptik thermal imager integrated into the system. The DMSC's four channels were configured to a specific wavelength (color) combination designed to maximize detection of the PLOO wastewater signature by differentiating between the wastefield and coastal turbidity plumes. Depth of penetration for this sensor varies between 7–15 m depending on water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 m. Fifteen DMSC overflights were conducted in 2009, which consisted of one to three flights per month during winter when the plume surfacing potential was greatest and when rainfall was typically highest. In contrast, only three surveys were flown during the spring and late summer months.

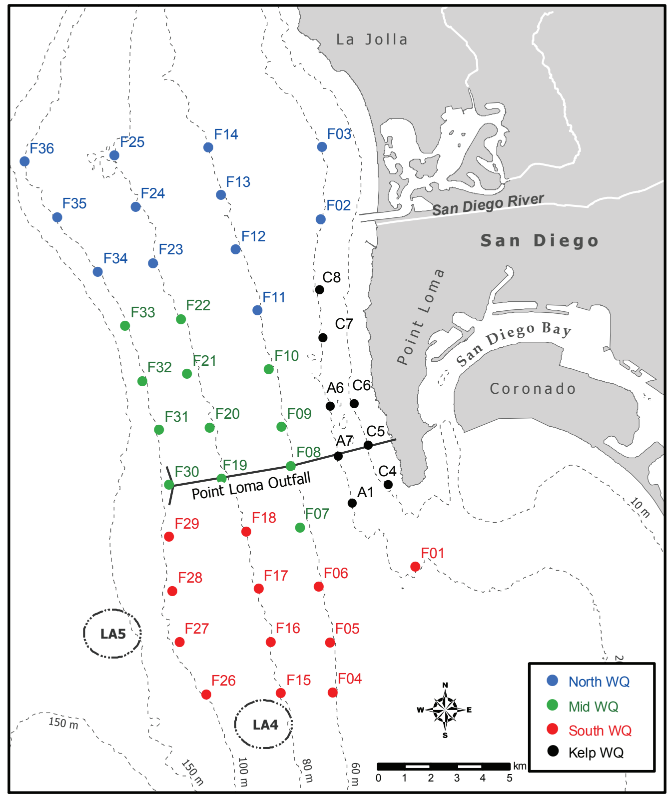


Figure 2.1
Water quality monitoring stations where CTD casts are taken, Point Loma Ocean Outfall Monitoring Program.

Data Treatment

The water column parameters measured in 2009 were summarized as quarterly means over all stations located along each of the 9, 18, 60, 80, and 98-m depth contours to provide an overview of trends throughout the entire survey area (i.e., across all depth contours). For spatial analysis, 3-dimensional graphical views were created using Interactive Geographical Ocean Data System software (IGODS), which uses a linear interpolation between stations and with depth at each site. Data for these analyses were limited to the 9, 18, 60, and 98-m depth contours to maximize visualization of the water column at these depths. Additional analysis included vertical profiles using the 1-m binned data for each parameter measured at the three offshore stations nearest the discharge site (see Figure 2.1). These included station F30 located within about 120 m of the center of the wye, station F31 located about 1.4 km north of the end of the northern diffuser leg, and station F29 located about 1.2 km south of the end of the southern diffuser leg. These profiles were created to provide a more detailed view of data depicted in the IGODS graphics. Finally, a time series of "anomalies" for each parameter was created to evaluate significant oceanographic events in the region between 1991–2009. The anomalies were calculated by subtracting the monthly means for each year from the mean of all 19 years combined. These mean values were calculated using data for the three stations described above, with all depths combined.

Results and Discussion

Oceanographic Conditions in 2009

Water temperature

In 2009, mean surface temperatures across the entire PLOO region ranged from 14.4°C in February to 20.6°C in August, while bottom temperatures averaged from 9.6°C in May to 14.7°C in November (Table 2.1). Although the offshore data are limited to only four surveys per year, ocean temperatures appeared to vary by season as expected, with

Table 2.1

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the PLOO region during 2009. Values are expressed as means for each survey pooled over all stations along each depth contour.

		Feb	May	Aug	Sep			Feb	May	Aug	Sep
Temperature (°C)						**pH**					
9-m	Surface	14.4	15.7	19.6	16.3	9-m	Surface	8.1	8.2	8.2	8.0
	Bottom	13.9	11.6	13.7	14.7		Bottom	8.0	7.9	8.0	7.9
18-m	Surface	14.4	16.5	18.1	16.1	18-m	Surface	8.1	8.3	8.2	8.1
	Bottom	13.0	10.6	12.5	14.2		Bottom	8.0	7.8	8.0	8.0
60-m	Surface	14.4	16.3	20.1	16.1	60-m	Surface	8.1	8.2	8.3	8.0
	Bottom	11.6	9.9	11.1	12.4		Bottom	7.8	7.7	7.8	7.9
80-m	Surface	14.5	17.2	20.2	16.7	80-m	Surface	8.1	8.3	8.2	8.1
	Bottom	11.1	9.7	10.4	11.9		Bottom	7.7	7.6	7.8	7.9
98-m	Surface	14.4	17.1	20.6	17.0	98-m	Surface	8.1	8.3	8.2	8.1
	Bottom	10.7	9.6	10.1	11.3		Bottom	7.7	7.6	7.7	7.8
Salinity (ppt)						**Transmissivity (%)**					
9-m	Surface	33.31	33.64	33.50	33.32	9-m	Surface	74	66	75	81
	Bottom	33.39	33.78	33.46	33.27		Bottom	79	77	84	83
18-m	Surface	33.25	33.63	33.51	33.31	18-m	Surface	76	72	78	85
	Bottom	33.51	33.84	33.43	33.25		Bottom	79	79	87	83
60-m	Surface	33.26	33.61	33.53	33.32	60-m	Surface	80	75	78	89
	Bottom	33.57	33.95	33.51	33.31		Bottom	83	87	84	86
80-m	Surface	33.31	33.60	33.54	33.37	80-m	Surface	82	83	79	89
	Bottom	33.72	34.04	33.65	33.37		Bottom	90	89	87	87
98-m	Surface	33.34	33.56	33.55	33.39	98-m	Surface	84	83	82	89
	Bottom	33.83	34.11	33.79	33.50		Bottom	92	90	91	88
Dissovled Oxygen (mg/L)						**Chlorophyll *a* (µg/L)**					
9-m	Surface	7.1	7.7	7.5	8.0	9-m	Surface	1.9	9.7	3.5	3.1
	Bottom	7.0	4.1	6.2	7.4		Bottom	2.7	9.9	4.5	4.3
18-m	Surface	7.9	8.1	7.6	8.5	18-m	Surface	2.0	12.2	5.7	3.3
	Bottom	6.4	3.0	5.6	7.6		Bottom	1.8	5.5	3.0	3.7
60-m	Surface	7.5	8.6	7.9	7.8	60-m	Surface	2.1	8.4	3.9	1.9
	Bottom	4.7	2.8	4.6	6.0		Bottom	0.7	0.4	0.9	1.9
80-m	Surface	7.7	8.6	7.7	7.7	80-m	Surface	2.4	2.2	2.6	1.5
	Bottom	4.1	2.5	4.1	5.6		Bottom	0.3	0.3	0.5	1.2
98-m	Surface	7.8	8.6	7.6	7.6	98-m	Surface	2.9	1.9	2.6	1.6
	Bottom	3.6	2.3	3.9	5.0		Bottom	0.2	0.3	0.4	0.7

no discernable patterns relative to wastewater discharge (Figure 2.2, 2.3). For example, the lowest temperatures of the year occurred during May at bottom depths along all depth contours, which probably reflected typical spring upwelling in the region. Thermal stratification also followed

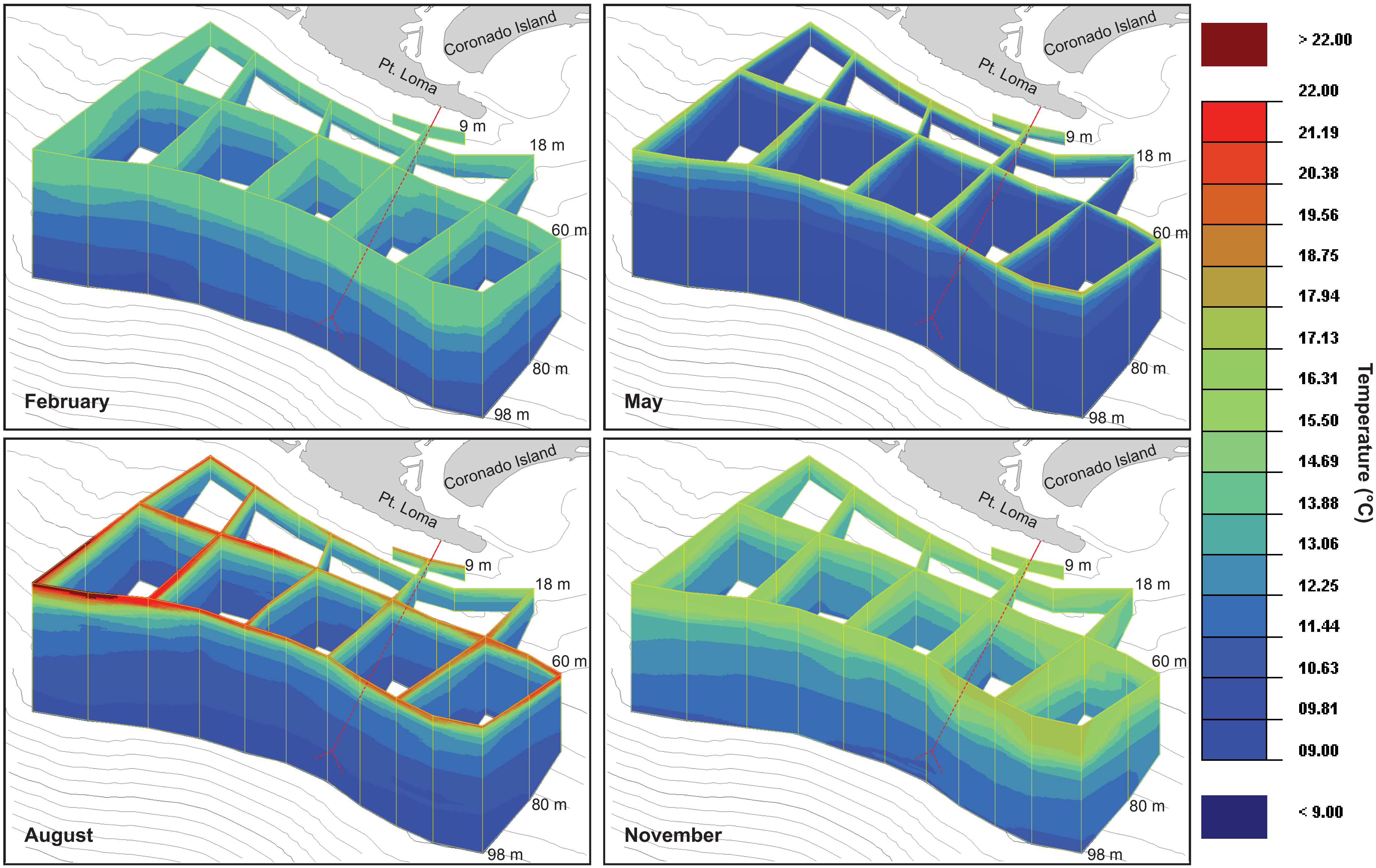


Figure 2.2

Ocean temperatures recorded in 2009 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

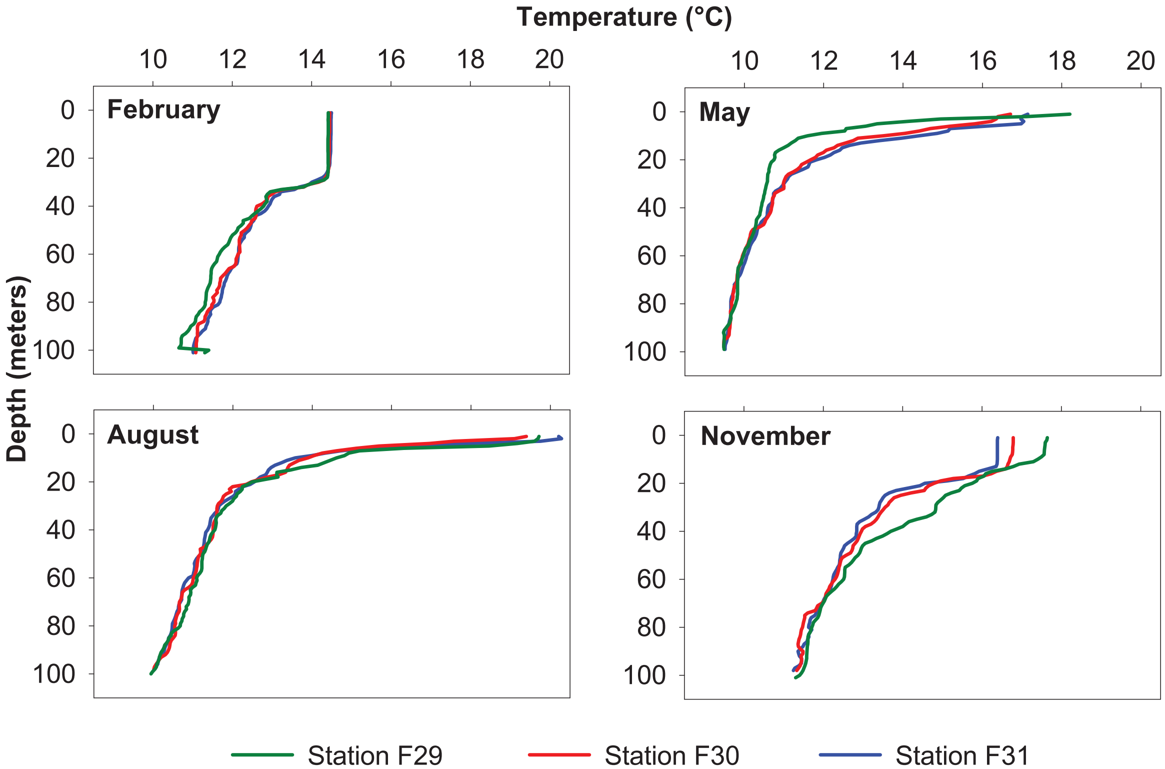


Figure 2.3
Vertical profiles of ocean temperature for PLOO stations F29, F30, and F31 during 2009.

expected seasonal patterns, with the water column ranging from weakly stratified in winter (i.e., February), to highly stratified in spring and summer (i.e., May and August), to weakly stratified in the fall (i.e., November). Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures are important to limiting the surface potential of the wastefield throughout the year. Moreover, the PLOO wastewater plume was not detected in surface waters at any time during the year based on remote sensing observations (see Svejkovsky 2010) or the results of discrete bacteriological samples (see Chapter 3).

Salinity

Average salinities for the region ranged from a low of 33.25 ppt in February to a high of 33.64 ppt in May for surface waters, and from 33.25 ppt in November to 34.11 ppt in May at bottom depths (Table 2.1). High salinity values at bottom depths extended across the entire region in May (Figure 2.4) and corresponded to the lower temperatures found at bottom depths as described above. Taken together, these factors are indicative of coastal upwelling that is typical for this time of year (Jackson 1986). There was some evidence of another region-wide phenomenon that occurred during the summer and fall, when a layer of water with relatively low salinity values occurred at mid-water (i.e., sub-surface) depths between about 10 and 60 m (see Figures 2.4 and 2.5). It seems unlikely that this sub-surface salinity minima (SSM) could be due to the PLOO wastewater plume for several reasons. For example, corresponding changes indicative of the wastewater plume were not evident in any of the other oceanographic data (e.g., depressed transmissivity). Additionally, most discrete seawater samples collected at the same depths and times as the oceanographic data did not contain elevated levels of indicator bacteria (see Chapter 3). Finally, similar SSMs have been reported previously off San Diego and elsewhere in southern California, including: (1) the South Bay outfall monitoring region during the summer of 2009 (City of San Diego 2010); (2) coastal waters

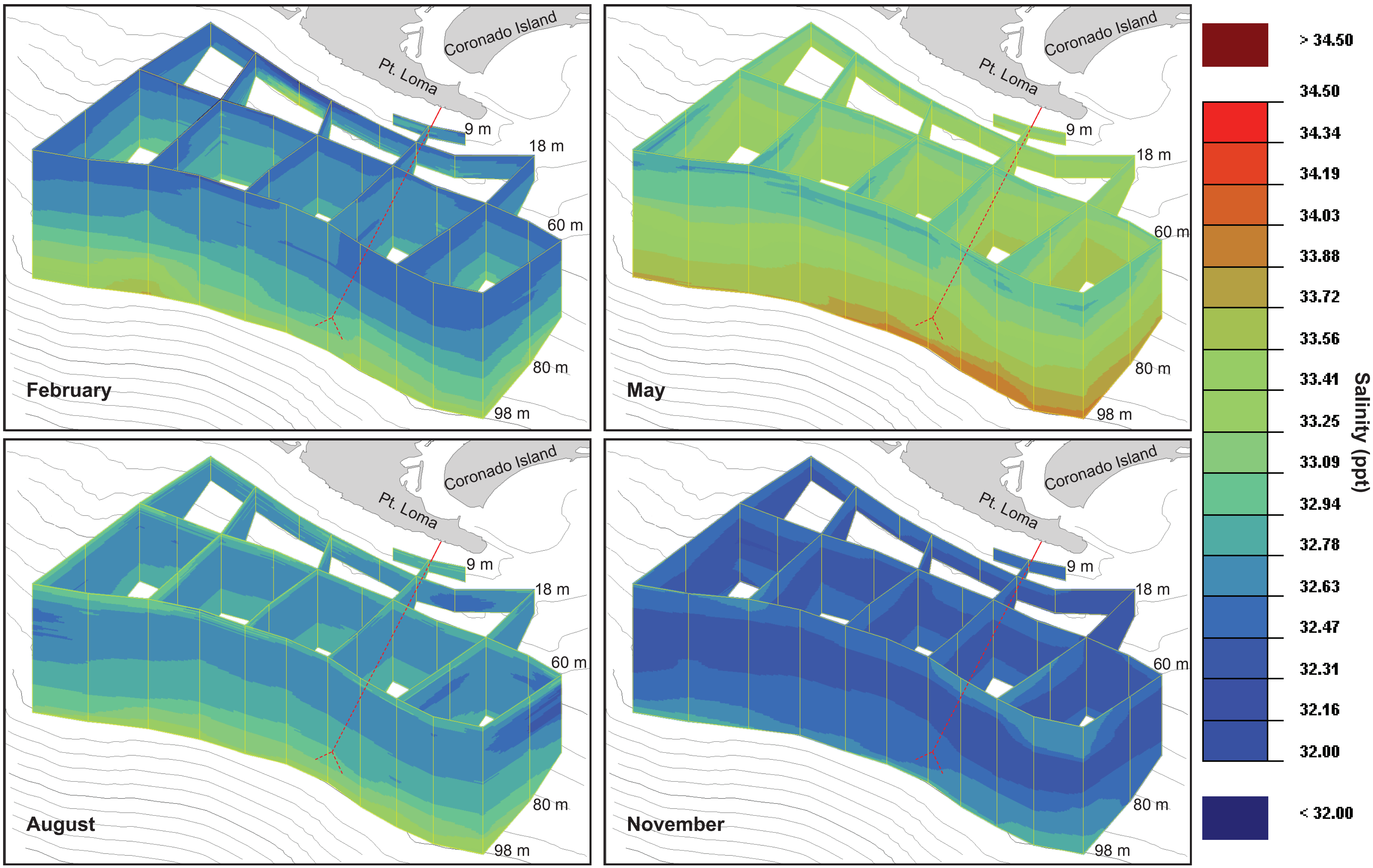


Figure 2.4

Levels of salinity recorded in 2009 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

off Orange County, California for many years (e.g., Orange County Sanitation District 1999); (3) extending as far north as Ventura, California (Orange County Sanitation District 2009). Further investigations are required to determine the possible source(s) of this phenomenon.

In addition to the region-wide phenomena described above, salinity levels were only slightly different at the three stations nearest the discharge site during the year (Figure 2.5). During February and November, for example, salinity values at depths between 60–90 m were lower at station F30 near the center of the wye and station F31 north of the discharge site than at station F29 to the south. In contrast, salinity values were lower at stations F30 and F29 at these same depths during May. However, salinity values at F30 never differed by more than 0.15 ppt from the other two stations, which was too small to even be apparent in the 3-D visualizations (i.e., Figure 2.4).

Density

Seawater density is a product of temperature, salinity and pressure, which in the shallower coastal waters of southern California is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, changes in density typically mirror those in water temperatures. This relationship was true in the Point Loma region during 2009. For example, differences between surface and bottom water densities resulted in moderate to weak pycnoclines at depths between about 10–30 m in February and November, and stronger pycnoclines at depths between 3–20 m in May and August (see Appendices A.2 and A.3).

Dissolved oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 7.1 to 8.6 mg/L in surface waters and from 2.3 to 7.6 mg/L in bottom waters across the Point Loma region in 2009, while mean pH values ranged from 8.0 to 8.3 in surface waters and from 7.6 to 8.0 in bottom waters (Table 2.1). Changes in pH were closely linked to changes in DO since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Variations in both parameters throughout the water column also followed normal seasonal patterns, with the greatest differences and therefore maximum stratification occurring during the spring and summer (see Appendices A.4, A.5 and A.6). The low DO values at mid- to bottom depths across the survey area during the spring may be due to cold, saline and oxygen poor ocean water that moves inshore during periods of coastal upwelling as suggested by the temperature and salinity results described above. In contrast, very high DO values at depths of about 20 m and shallower (i.e., coincident with the pycnocline) during May were likely due to phytoplankton blooms; i.e., these high DO values corresponded with high chlorophyll values recorded at the same time and depths.

Some differences in DO and pH levels occurred at the three stations nearest the outfall discharge site, primarily during November (see Appendix A.5). This included lower DO and pH values at stations F30 and F31 than at station F29 during this month, although these differences were very small (i.e., <1 mg/L for DO, and <0.1 units for pH). The low values for these parameters did not appear to extend much beyond these two stations (see Appendices A.4 and A.6).

Transmissivity

Transmissivity appeared to be within normal ranges in the PLOO region during 2009 with average values of 66–89% on the surface and 77–92% in bottom waters (Table 2.1). Water clarity was consistently greater at the offshore sites than in inshore waters, by as much as 16% at the surface and 13% near the bottom. Reduced water clarity at surface and mid-water depths tended to co-occur with peaks in chlorophyll concentrations associated with phytoplankton blooms (see Svejkovsky 2010, and Appendices A.7, A.8 and A.9). Lower transmissivity during the winter and fall months at the stations located inshore along the 9 and 18-m depth contours may also have been due to wave and storm activity. In contrast, reductions in transmissivity that occurred offshore at depths greater than 60 m were more likely associated with wastewater discharge from the PLOO. Reductions in water clarity at the three stations nearest the discharge site were most evident

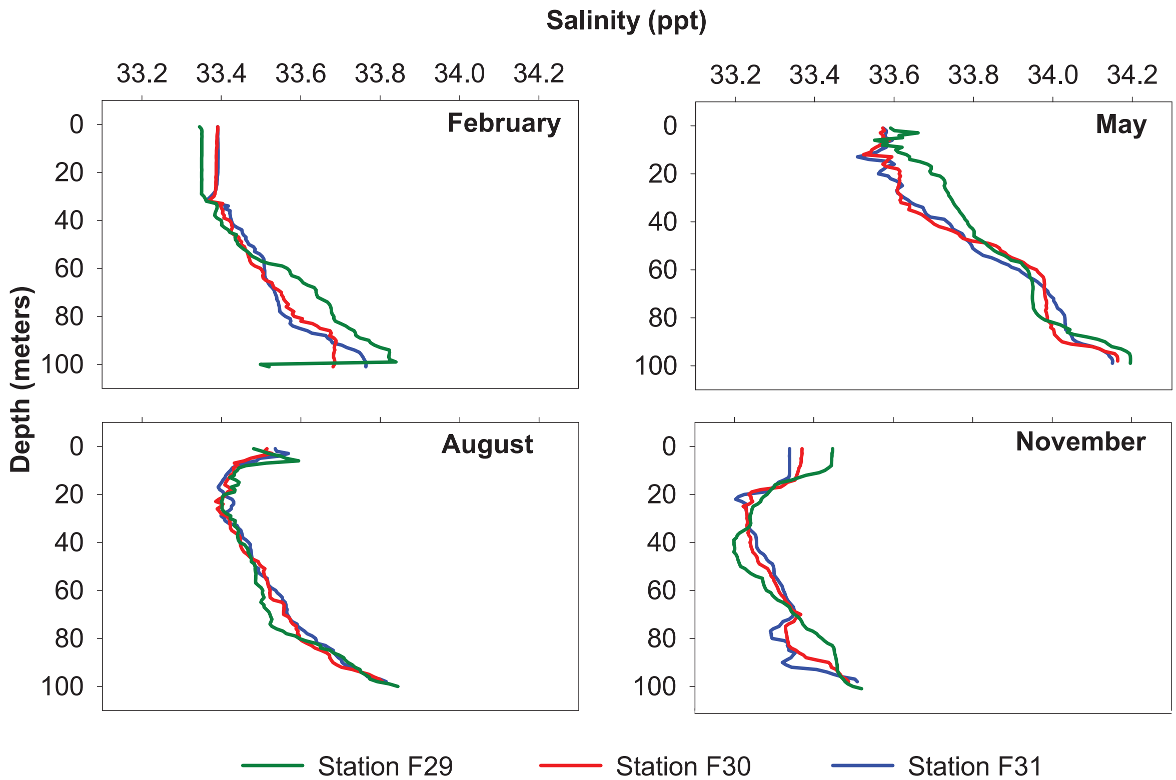


Figure 2.5
Vertical profiles of salinity for PLOO stations F29, F30, and F31 during 2009.

in May and November (see Appendix A.8), which was coincident with some of the lower salinity, DO and pH values discussed above, especially in November. Similar to these other parameters, differences in water clarity were relatively small (<6%) and localized (e.g., Appendix A.7).

***Chlorophyll* a**

Mean chlorophyll concentrations at the offshore sites ranged from 0.2 µg/L near the bottom in February to 12.2 µg/L at the surface in May (Table 2.1). However, further analysis clearly showed that the highest chlorophyll values tended to occur at sub-surface depths coincident with the pycnocline each season (Appendix A.9). These results reflect the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrient levels are greatest. The highest concentrations of chlorophyll for 2009 were observed 10–20 m below the surface during May across much of the region. These high values corresponded to a phytoplankton bloom observed by remote sensing extending along the entire San Diego County coastline on May 7, 2009 (Svejkovsky 2010). They were also coincident with the coastal upwelling event indicated by the very low temperatures, high salinity and low DO values at bottom depths described above. The relationship between coastal upwelling and subsequent plankton blooms has been well documented by remote sensing imagery over the years (e.g., Svejkovsky 2009, 2010).

Historical Assessment of Oceanographic Conditions

A review of 19 years (1991–2009) of oceanographic data collected at stations F29, F30 and F31 located near the discharge site along the 98-m depth contour revealed no measurable impact that can be attributed to wastewater discharge via the PLOO (Figure 2.6). Although the change from monthly to quarterly sampling in late 2003 has reduced the number of data points for interpretation, results for the region are still consistent with described changes in large-scale patterns in the California Current System (CCS) (see Peterson et al. 2006, McClatchie et al. 2008, 2009). For example, five major events have

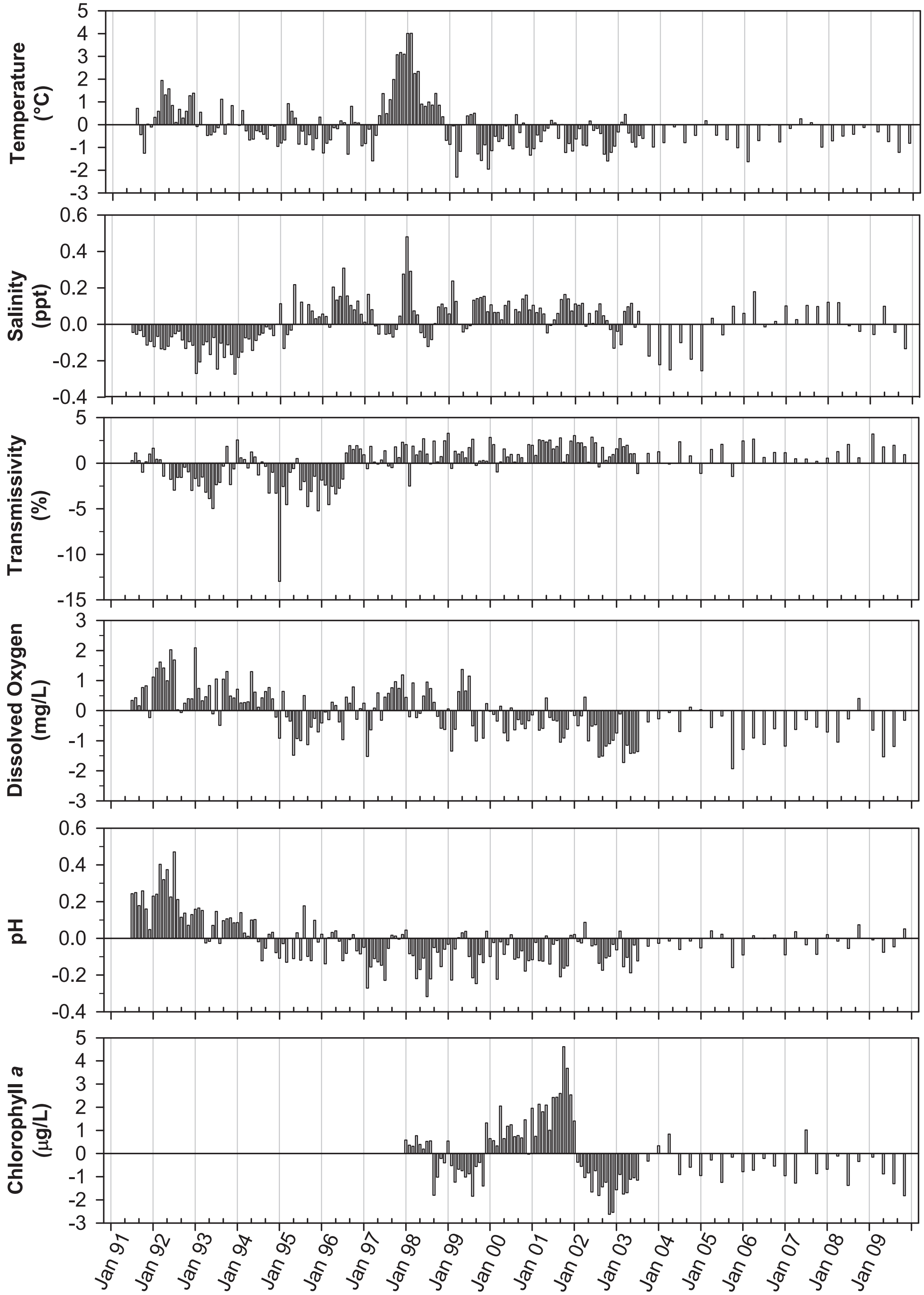


Figure 2.6

Time series of temperature, salinity, transmissivity, dissolved oxygen, pH, and chlorophyll anomalies between 1991 and 2009. Anomalies were calculated by subtracting monthly means for each year (1991–2009) from the mean of all 19 years combined; data were limited to stations F29, F30, and F31, all depths combined.

affected the CCS during the last decade: (1) the 1997–1998 El Niño; (2) a shift to cold ocean conditions between 1999–2002; (3) a more subtle but persistent return to warm ocean conditions beginning in October 2002; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 in conjunction with cooling of the Pacific Decadal Oscillation (PDO). Temperature and salinity data for the Point Loma region are consistent with all but the third of these events.

Water clarity (transmissivity) around the outfall has tended to be higher than the historical average since about mid-1996 (Figure 2.6). This may be due in part to relatively low values that occurred in 1995 and early 1996, perhaps related to factors such as sediment plumes associated with offshore disposal of dredged materials from a large dredging project in San Diego Bay. Subsequent reductions in transmissivity during some winters (e.g., 1998 and 2000) appear to be the result of increased amounts of suspended sediments associated with strong storm activity (e.g., see NOAA/NWS 2010).

There have been no apparent trends in DO concentrations or pH values related to the PLOO discharge (Figure 2.6). These parameters are complex, dependent on water temperature and depth, and sensitive to physico-chemical and biological processes (Skirrow 1975). Moreover, DO and pH are subject to diurnal and seasonal variations that make temporal changes difficult to evaluate. However, DO values below the historical average appear to be related to low levels of chlorophyll or periods of strong upwelling.

Summary and Conclusions

The Point Loma outfall region was characterized by relatively normal oceanographic conditions in 2009, which included coastal upwelling and corresponding phytoplankton blooms such as red tides that were strongest during the spring and occurred across the entire region. Upwelling was indicated by relatively cold, dense, saline waters with low DO levels. Plankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations. Additionally, water column stratification followed typical patterns for the San Diego region, with maximum stratification occurring in mid-summer and reduced stratification during the winter and fall. Further, oceanographic conditions for the region remained consistent with other well documented large-scale patterns (e.g., Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009). These observations suggest that other factors such as upwelling of deep ocean waters and large-scale climatic events such as El Niños and La Niñas continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

Satellite and aerial imagery observations conducted during 2009 revealed no evidence of the wastewater plume reaching near-surface waters, even during the winter and fall months when the water column was only weakly stratified (Svejkovsky 2010). This is consistent with the results from the bacteriological surveys (see Chapter 3), which further support the conclusion that the plume did not surface during the year. These findings were also supported this past year by the application of new IGODS analytical techniques to the oceanographic data collected by the City's ocean monitoring program. While small differences were observed at stations close to the outfall discharge site, it was clear from these analyses that any variations among stations at any particular depth were very slight and highly localized.

Literature Cited

Bowden, K.F. (1975). Oceanic and Estuarine Mixing Processes. In: J.P. Riley and G. Skirrow (eds.). Chemical Oceanography, 2nd Ed., Vol. 1. Academic Press, San Francisco. p 1–41.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Dailey, M.D., D.J. Reish, and J.W. Anderson, eds. (1993). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

Dayton, P., P.E. Parnell, L.L. Rasmussen, E.J. Terrill, and T.D. Stebbins. (2009). Point Loma Ocean Outfall Plume Behavior Study, Scope of Work. Scripps Institution of Oceanography, La Jolla, CA, and City of San Diego, Metropolitan Wastewater Department, San Diego, CA. [NOAA Award No. NA08NOS4730441]

Goericke, R., E. Venrick, T. Koslow, W.J. Sydeman, F.B. Schwing, S.J. Bograd, B. Peterson, R. Emmett, K.R. Lara Lara, G. Gaxiola-Castro, J.G. Valdez, K.D. Hyrenbach, R.W. Bradley, M. Weise, J. Harvey, C. Collins, and N. Lo. (2007). The state of the California Current, 2006–2007: Regional and local processes dominate. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 48: 33–66.

Jackson, G.A. (1986). Physical Oceanography of the Southern California Bight. In: R. Eppley (ed.). Plankton Dynamics of the Southern California Bight. Springer Verlag, New York. p 13–52.

Largier, J., L. Rasmussen, M. Carter, and C. Scearce. (2004). Consent Decree — Phase One Study Final Report. Evaluation of the South Bay International Wastewater Treatment Plant Receiving Water Quality Monitoring Program to Determine Its Ability to Identify Source(s) of Recorded Bacterial Exceedances. Scripps Institution of Oceanography, University of California, San Diego, CA.

Mann, K.H. (1982). Ecology of Coastal Waters, A Systems Approach. University of California Press, Berkeley.

Mann. K.H. and J.R.N. Lazier. (1991). Dynamics of Marine Ecosystems, Biological–Physical Interactions in the Oceans. Blackwell Scientific Publications, Boston.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, G. Gaxiola-Castro, R. Durazo, M. Kahru, B.G. Mitchell, K.D. Hyrenbach, W.J. Sydeman, R.W. Bradley, P. Warzybok, and E. Bjorkstedt. (2008). The state of the California Current, 2007–2008: La Niña conditions and their effects on the ecosystem. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 49: 39–76.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, J. Gomez-Valdes, B.E. Lavaniegos, G. Gaxiola-Castro, B.G. Mitchell, M. Manzano-Sarabia, E. Bjorkstedt. S. Ralston, J. Field, L. Rogers-Bennet, L. Munger, G. Campbell, K. Merkens, D. Camacho, A. Havron, A. Douglas, and J. Hildebrand (2009). The state of the California Current, Spring 2008–2009: Cold conditions drive regional differences in coastal production. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 50: 43–68.

NOAA/NWS. (2010). The National Oceanic and Atmospheric Association and the National Weather Service Archive of Local Climate Data for San Diego, CA. http://www.wrh.noaa.gov/sgx/obs/rtp/linber.html.

Ocean Imaging. (2010). Ocean Imaging Corporation archive of aerial and satellite-derived images.

http://www.oceani.com/SanDiegoWater/index.html.

Orange County Sanitation District. (1999). Annual Report, July 1998–June 1999. Marine Monitoring, Fountain Valley, CA.

Orange County Sanitation District. (2009). Annual Report, July 2008–June 2009. Marine Monitoring, Fountain Valley, CA.

Parnell, E., and L. Rasmussen. (2010). Summary of PLOO hydrographic observations (2006–2009). Draft report to City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Peterson, B., R. Emmett, R. Goericke, E. Venrick, A. Mantyla, S.J. Bograd, F.B. Schwing, R. Hewitt, N. Lo, W. Watson, J. Barlow, M. Lowry, S. Ralston, K.A. Forney, B.E. Lavaniegos, W.J. Sydeman, D. Hyrenbach, R.W. Bradley, P. Warzybok, F. Chavez, K. Hunter, S. Benson, M. Weise, J. Harvey, G. Gaxiola-Castro, and R. Durazo. (2006). The state of the California Current, 2005–2006: Warm in the north, cool in the south. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 47: 30–74.

Pickard, D.L. and W.J. Emery. (1990). Descriptive Physical Oceanography. 5th Ed. Pergamon Press, Oxford.

Skirrow, G. (1975). Chapter 9. The Dissolved Gases — Carbon Dioxide. In: Chemical Oceanography. J.P. Riley and G. Skirrow (eds.). Academic Press, London.

Storms, W.E., T.D. Stebbins, and P.E. Parnell. (2006). San Diego Moored Observation System Pilot Study Workplan for Pilot Study of Thermocline and Current Structure off Point Loma, San Diego, California. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Scripps Institution of Oceanography, La Jolla, CA.

Svejkovsky J. (2009). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2008 – 31 December 2008. Solana Beach, CA.

Svejkovsky J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2009 – 31 December 2009. Solana Beach, CA.

Terrill, E., K. Sung Yong, L. Hazard, and M. Otero. (2009). IBWC/Surfrider — Consent Decree Final Report. Coastal Observations and Monitoring in South Bay San Diego. Scripps Institution of Oceanography, University of California, San Diego, CA.

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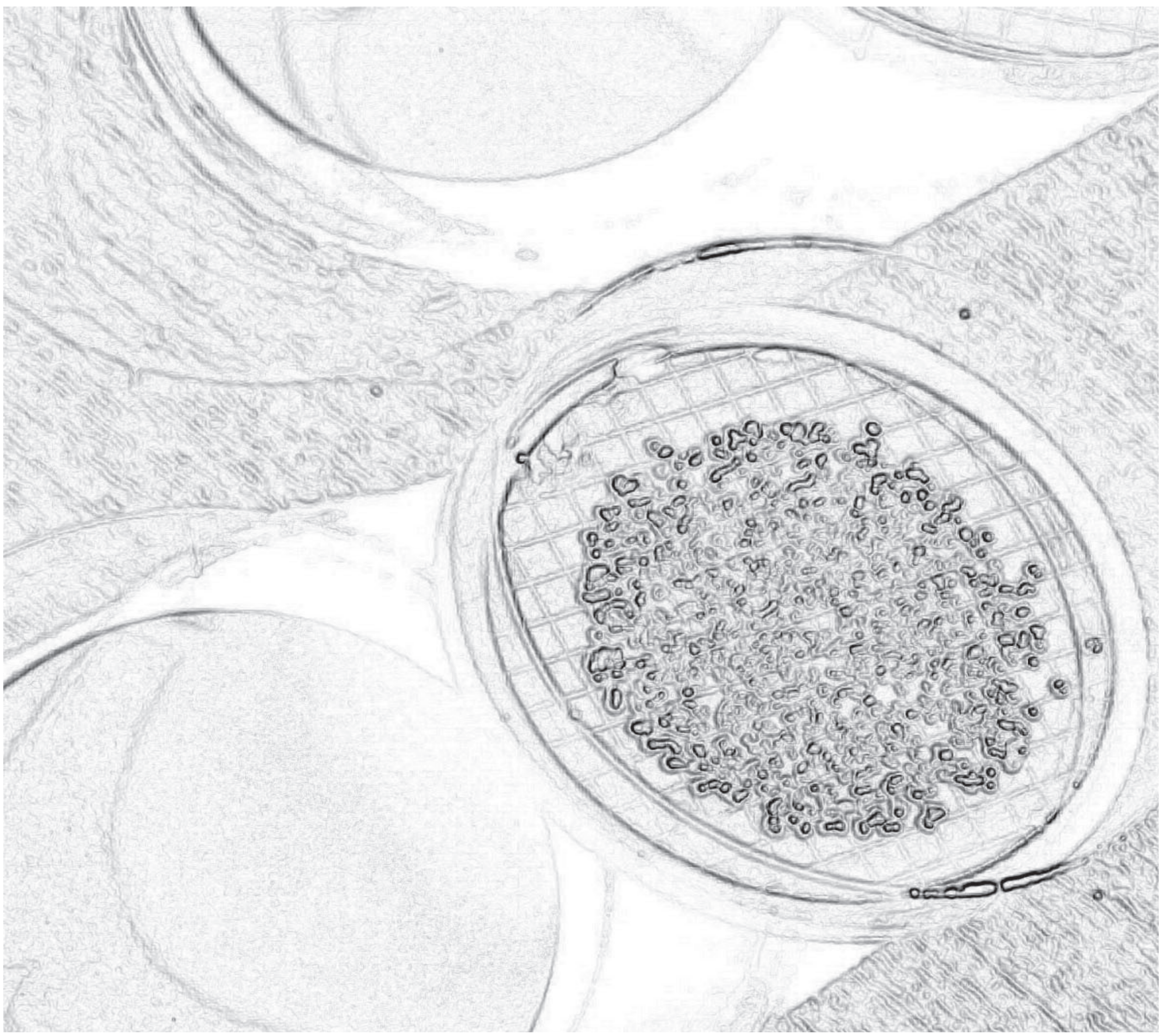
Chapter 3
Water Quality



Chapter 3. Water Quality

INTRODUCTION

The City of San Diego monitors water quality along the shoreline and in offshore ocean waters for the region surrounding the Point Loma Ocean Outfall (PLOO). This aspect of the City's ocean monitoring program is designed to assess general oceanographic conditions, evaluate patterns in movement and dispersal of the PLOO wastewater plume, and monitor compliance with water contact standards as defined in the 2001 California Ocean Plan (COP). Results of all sampling and analyses, including COP compliance summaries, are submitted to the San Diego Regional Water Quality Control Board in the form of monthly receiving waters monitoring reports. Densities of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms, and enterococcus, are measured and evaluated along with data on local oceanographic conditions (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall. Evaluation of these data may also help to identify other point or non-point sources of bacterial contamination (e.g., outflows from rivers or bays, surface runoff from local watersheds). This chapter summarizes and interprets patterns in seawater FIB concentrations collected for the Point Loma region during 2009.

Materials and Methods

Field Sampling

Seawater samples for bacteriological analyses were collected at a total of 52 shore, kelp bed, or other offshore monitoring sites during 2009 (Figure 3.1). Sampling was performed weekly at eight shore stations (i.e., stations D4, D5, and D7–D12) to monitor FIB concentrations in waters adjacent to public beaches and to evaluate compliance with the COP water contact standards (see Box 3.1). Eight stations located in nearshore waters within the Point Loma kelp forest were also monitored weekly to assess water quality conditions and COP compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These include stations C4, C5, and C6 located near the inner edge of the kelp bed along the 9-m depth contour, and stations A1, A6, A7, C7, and C8 located near the outer edge of the kelp bed along the 18-m depth contour.

An additional 36 stations located further offshore were sampled in order to monitor FIB levels in these deeper waters and estimate dispersion of the wastewater plume. These offshore stations are arranged in a grid surrounding the discharge site along or adjacent to the 18, 60, 80, and 98-m depth contours (Figure 3.1). The stations were sampled quarterly during the months of February, May, August and November, with each survey occurring

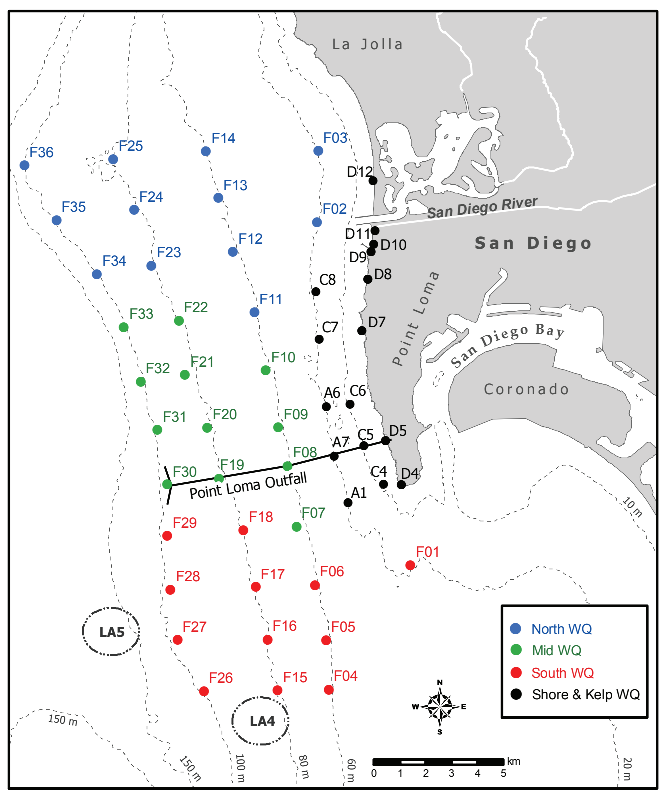


Figure 3.1
Water quality monitoring stations for the Point Loma Ocean Outfall Monitoring Program.

Box 3.1

Bacteriological compliance standards for water contact areas, 2001 California Ocean Plan (SWRCB 2001). CFU = colony forming units.

(a) *30-day Total Coliform Standard* — no more than 20% of the samples at a given station in any 30-day period may exceed a concentration of 1000 CFU/100 mL.

(b) *10,000 Total Coliform Standard* — no single sample, when verified by a repeat sample collected within 48 hrs, may exceed a concentration of 10,000 CFU/100 mL.

(c) *60-day Fecal Coliform Standard* — no more than 10% of the samples at a given station in any 60-day period may exceed a concentration of 400 CFU/100 mL.

(d) *30-day Fecal Geometric Mean Standard* — the geometric mean of the fecal coliform concentration at any given station in any 30-day period may not exceed 200 CFU/100 mL, based on no fewer than five samples.

over three days. For sampling and analysis purposes, these 36 stations are grouped as follows: (a) stations F02, F03, F11–F14, F23–F25, and F34–F36 comprise the 12 northern water quality (North WQ) sites; (b) stations F07–F10, F19–F22, and F30–F33 comprise the 12 mid-region water quality (Mid-WQ) sites; (c) stations F01, F04–F06, F15–F18, and F26–F29 comprise the 12 southern water quality (South WQ) sites. All stations within each of these three groups are sampled on a single day during each quarterly survey. See Appendix A.1 for the specific dates these surveys were conducted in 2009.

In addition, three other stations (A11, A13, A17) located seaward of the kelp bed were sampled voluntarily as part of the weekly sampling to monitor water quality near the original PLOO discharge site (i.e., pre-1994). Analysis of data for these three stations is not included herein, but has been reported elsewhere (see City of San Diego 2009a, 2010a).

Seawater samples for the shore stations were collected from the surf zone in sterile 250-mL bottles. Additionally, visual observations of water color,

Table 3.1

Depths at which seawater samples are collected for bacteriological analysis at the PLOO kelp bed and offshore stations.

Station Contour	Sample Depth (m) 1	3	9	12	18	25	60	80	98
Kelp Bed									
9 m	x	x	x						
18 m	x			x	x				
Offshore									
18 m	x			x	x				
60 m	x					x	x		
80 m	x					x	x	x	
98 m	x					x	x	x	x

surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) where they were analyzed to determine FIB concentrations (i.e., total coliform, fecal coliform, and enterococcus bacteria).

Seawater samples for the kelp bed and offshore stations were collected at 3–5 discrete depths per site dependent upon station depth (see Table 3.1) and analyzed for the above FIBs. These samples were collected using either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles. Aliquots for total coliform, fecal coliform and enterococcus analysis were drawn into appropriate sample containers. These samples were refrigerated onboard ship and then transported to the CSDMML for processing and analysis. Visual observations of weather and sea conditions, as well as human or animal activity were also recorded at the time of sampling.

Laboratory Analyses and Data Treatment

The CSDMML follows guidelines issued by the United States Environmental Protection Agency (U. S. EPA) Water Quality Office, Water Hygiene Division, and the California State Department of Health Services (CDHS) Environmental Laboratory

Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1998). These guidelines dictate holding times, filtration techniques, procedures for counting colonies of indicator bacteria, calculation and interpretation of results, data verification and reporting. For example, all bacterial analyses were performed within 8 hours of sample collection and conformed to standard membrane filtration techniques (see APHA 1998). In addition, plates with FIB counts above or below ideal counting ranges were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were excluded and the counts treated as discrete values when calculating means and in determining compliance with COP standards. Further, routine quality assurance tests were performed on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intrasample and inter-analyst variability, respectively. Results of these procedures for 2009 were reported in City of San Diego (2010b).

Bacteriological benchmarks defined in the 2001 COP and Assembly Bill 411 (AB 411) were used as reference points to distinguish elevated FIB values in receiving water samples discussed in this report. These benchmarks are: (a) >1000 CFU/100 mL for total coliforms; (b) >400 CFU/100 mL for fecal coliforms; (c) >104 CFU/100 mL for enterococcus. Data were summarized for analysis by counting the number of samples with FIB levels higher than one or more of these benchmarks. Furthermore, any water sample with total coliforms ≥1000 CFU/100 mL and a fecal:total ratio ≥0.1 was considered representative of contaminated waters (see CDHS 2000). This condition is referred to as the Fecal:Total Ratio (FTR) criterion herein.

Results and Discussion

Shore Stations

As in previous years, concentrations of indicator bacteria were generally low along the Point Loma shoreline in 2009. Monthly FIB densities at the individual shore stations averaged about 2–4031 CFU/100 mL for total coliforms, 2–194 CFU/100 mL for fecal coliforms, and 2–2841 CFU/100 mL for enterococcus (Appendix B.1). Out of the 480 discrete seawater samples collected during 2009, none met the FTR criterion for contaminated waters. In addition, 14 of the 20 samples with elevated FIBs were collected during the wet season during or shortly after rainfall events (Table 3.2), which occurred primarily in January, February, and December (Appendix B.2). Of these 14 samples, eight had elevated densities of just enterococcus, four had elevated densities of just total coliforms, one had elevated densities of both total coliforms and enterococcus, and one had elevated densities of both fecal coliforms and enterococcus.

Table 3.2
The number of samples with elevated FIBs collected at PLOO shore stations during 2009. Wet season = January–April and November–December; dry season = May–October; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed from north to south from top to bottom.

	Season		
Station	Wet	Dry	Total
D12	1	1	2
D11	3	0	3
D10	2	0	2
D9	1	0	1
D8	5	4	9
D7	2	0	2
D5	0	0	0
D4	0	1	1
Rain (in)	5.29	0.21	5.5
Total	14	6	20
n	240	240	480

The other six samples with elevated FIB densities occurred during periods without any measurable rainfall (Table 3.2). These included one sample collected at station D4 in October, four samples collected at station D8 during June and October, and one sample collected at station D12 in July (Appendix B.2). Four of these samples contained elevated levels of enterococcus only, while one had elevated densities of fecal coliforms and entercoccus, and one had elevated densities of just

Table 3.3

Summary of FIB densities (CFU/100 mL) at PLOO kelp bed stations in 2009. Data are expressed as means for all stations along each depth contour by month; *n* = total number of samples per month.

Assay	Contour	*n*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	9 m	45	10	5	4	3	5	2	2	3	8	4	9	45
	18 m	75	7	6	8	3	7	3	2	3	19	4	5	903
Fecal	9 m	45	2	2	2	2	2	2	2	2	2	2	2	2
	18 m	75	2	2	2	2	3	2	2	2	2	2	2	3
Entero	9 m	45	2	2	2	2	4	8	2	12	6	4	15	7
	18 m	75	2	4	2	2	25	503	7	10	4	4	3	15

total coliforms. A possible source of contamination at station D8 is a tidally influenced storm drain (see Martin and Gruber 2005, Griffith et al. 2010), which has been suggested previously as a likely cause of high FIB counts in the area during dry periods (see City of San Diego 2005–2008, 2009b). Other sources that may contribute to bacterial contamination at station D8, as well as at stations D4 and D12, include beach wrack (i.e., decaying kelp and seagrass) and shorebirds (see Oshiro and Fujioka 1995, Arvanitidou et al. 2001, Grant et al. 2001, Griffith et al. 2010), all of which are commonly present during sampling times.

Kelp Bed Stations

Concentrations of indicator bacteria were also generally low at the eight kelp bed stations in 2009. For example, monthly FIB densities at these stations averaged about 2–903 CFU/100 mL for total coliforms, 2–3 CFU/100 mL for fecal coliforms, and 2–503 CFU/100 mL for enterococcus (Table 3.3). Of the 1440 seawater samples collected from these sites during the year, only 25 (1.7%) had elevated FIB concentrations, none of which exceeded the FTR criterion for contaminated waters (Appendix B.3). Eleven of the 25 samples with elevated FIBs were collected during the wet season and were likely associated with rainfall events (Table 3.4). Of these, eight samples had elevated counts of total coliforms, seven had elevated enterococcus levels, and none had elevated levels of fecal coliforms.

In contrast to previous years when very few seawater samples with elevated FIBs occurred in the Point Loma kelp forest during the dry season (e.g., see City of San Diego 2009b), 14 samples were collected at the kelp stations between May and August during 2009 (Table 3.4, Appendix B.3). However, these samples were collected only at stations A1, A6, A7, C7 and C8 located near the outer edge of the kelp bed. Additionally, these samples only had elevated levels of enterococcus, some of which were unusually high up to 12,000 CFU/100 mL (see Appendix B.3). Potential sources for these elevated enterococcus densities are unclear.

Offshore Stations

Average FIB densities per depth contour for the 36 offshore stations sampled quarterly during 2009 are presented in Table 3.5. Seawater samples from the shallowest 18-m stations had very low concentrations of total coliforms, fecal coliforms, and enterococcus averaging ≤14 CFU/100 mL during each survey. In contrast, FIB densities were typically higher at the deeper stations along the 60, 80, and 98-m transects, averaging up to 870 CFU/100 mL for totals, 384 CFU/100 mL for fecals, and 32 CFU/100 mL for enterococcus. All of the highest mean FIB values occurred during May at the 80-m stations. Overall, these average FIB values were lower in 2009 than during the previous five years (see City of San Diego 2005–2008, 2009b). This recent decrease in FIB densities may be associated with the implementation of chlorination and partial disinfection of PLOO effluent, which began near the end of 2008 and continues to present.

Of the 564 seawater samples collected at the offshore stations during the year, only 41 (~7.3%) contained elevated FIB densities (see Appendix B.4).

Table 3.4

The number of samples with elevated FIBs collected at PLOO kelp bed stations during 2009. Wet season = January–April and November–December; dry season = May–October; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed from north to south from top to bottom by depth contour.

Station	Season: Wet	Season: Dry	Total
18-m Depth Contour			
A6	2	4	6
A7	3	4	7
A1	2	2	4
C8	1	3	4
C7	1	1	2
9-m Depth Contour			
C6	0	0	0
C5	0	0	0
C4	2	0	2
Rain (in)	5.29	0.21	5.5
Total	11	14	25
n	720	720	1440

Individually, 39 samples had total coliform concentrations >1000 CFU/100 mL, 24 samples had fecal coliforms >400 CFU/100 mL, and 12 samples had enterococcus densities > 104 CFU/100 mL. Twenty-two of these samples had elevated levels of all three FIB types (*n* = 12) or just total and fecal coliforms (*n* = 10). A total of 38 samples (~6.7%) met the FTR criterion for contaminated seawater, which may be indicative of the PLOO wastefield; these included 33 of the samples with elevated totals plus five additional samples with totals equal to, but not exceeding 1000 CFU/100 mL. Figure 3.2 provides a comparison of the proportion of samples with elevated FIBs to those indicative of contaminated waters for each depth contour.

Patterns in the distribution of samples that exceeded the FTR criterion each quarter were evaluated to estimate possible dispersion of the PLOO wastefield during these surveys. All but one of these samples were collected from depths of 60 m or greater (see Figure 3.3). If these FIB counts and distributions do reflect the dispersion of contaminated waters associated with the wastefield, the results suggest that the wastewater plume remained restricted to relatively deep waters throughout the year.

Table 3.5

Summary of FIB densities (CFU/100 mL) at PLOO offshore stations in 2009. Data for each quarterly survey are expressed as means for all stations along each depth contour; *n* = total number of samples per survey.

Assay	Contour	*n*	Feb	May	Aug	Nov
Total	18 m	9	9	2	4	14
	60 m	33	134	657	45	12
	80 m	44	340	870	488	122
	98 m	55	99	851	567	746
Fecal	18 m	9	2	2	2	4
	60 m	33	17	127	7	3
	80 m	44	55	384	92	15
	98 m	55	13	314	106	231
Entero	18 m	9	2	2	2	5
	60 m	33	5	14	2	3
	80 m	44	8	32	17	7
	98 m	55	3	20	10	19

This conclusion is consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2009 (see Svejkovsky 2010). Additional comparisons also suggest that wastewater dispersion and plume transport varied both within and between survey periods (e.g., Figure 3.3). For example, the May and August surveys indicate a mixed northern and southern dispersion of the plume along the 60, 80 and 98-m depth contours. In contrast, the plume appeared to disperse primarily to the south in February and to the north in November. However, it should be noted that the offshore samples are collected over multiple days, and ocean conditions such as current direction can change daily (or even within a day). Even so, these results appear to align with preliminary current data for the region (e.g., Parnell and Rasmussen 2010).

California Ocean Plan Compliance

Compliance with the bacterial water contact standards specified in the 2001 COP (see Box 3.1) was very high in 2009 for the shore and kelp bed stations sampled off Point Loma (see Appendices B.5, B.6). For example, all of the kelp stations and six of the eight shore stations were in complete compliance with all four of the COP standards throughout the year. Only shore stations D8 and D11 fell below

100% compliance, with each of the exceedances occurring during winter "wet season" months. For example, the 30-day total coliform standard was exceeded at station D8 in January and at station D11 during February and March, resulting in 95% and 92% overall compliance with this standard, respectively. Station D11 also exceeded the 10,000 total coliform standard once in February, as well as the 60-day fecal coliform standard the following December. Both D8 and D11 were 100% compliant with the 30-day fecal geometric mean standard.

Summary and Conclusions

There was no evidence that wastewater discharged to the ocean via the PLOO reached shoreline or near-shore recreational waters in 2009. Although elevated FIB densities were occasionally detected along the shoreline and at the kelp bed stations throughout the year, concentrations of these bacteria tended to be relatively low overall. In fact, none of the seawater samples collected met the FTR criteria for contamination and only two samples with elevated levels of fecal coliform bacteria were collected in 2009 at these stations. In general, elevated FIB densities at shore and kelp bed stations were limited to instances when the source of contamination was likely associated with rainfall, seabirds, heavy recreational use, or decaying plant material (i.e., kelp and surfgrass). For example, most of the elevated bacterial densities occurred during February and December, which were some of the wettest months of the year. For these reasons, seawater samples from all of the kelp bed stations and all but two of the shore stations were 100% compliant with the four COP standards. The few exceedences for shore stations D8 and D11 corresponded to rain events or other sources of contamination unrelated to the PLOO discharge.

Previous analyses of water quality data for the region have indicated that the PLOO wastefield has typically remained well offshore and submerged in deep waters since the extension of the outfall was completed in late 1993 (e.g., City of San Diego 2007, 2008, 2009b). This pattern remained true for 2009

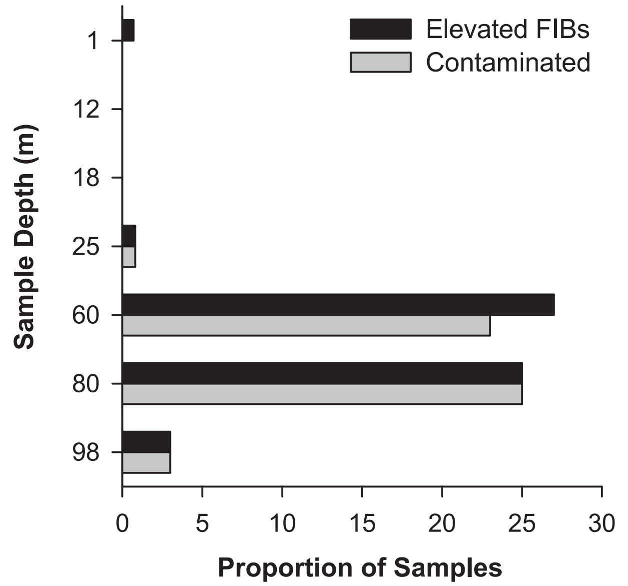


Figure 3.2
Summary of FIBs by depth for PLOO offshore stations in 2009. Data are expressed as the proportion of samples with elevated FIB densities and the proportion of samples that met FTR criterion indicative of contaminated seawater.

with evidence of the wastewater plume (i.e., samples with elevated FIBs and exceedences of the FTR criterion) being restricted to depths of 60 m or below in offshore waters. Moreover, no visual evidence of the plume surfacing was detected in aerial or satellite imagery during 2009 (Svejkovsky 2010). The 98-m depth of the discharge site may be the dominant factor that inhibits the plume from reaching surface waters. For example, wastewater released into these deep, cold and dense waters does not appear to mix with the top 25 m of the water column. Finally, it appears that not only is the plume from the PLOO being trapped below the thermocline, but now that effluent is undergoing chlorination prior to discharge, densities of indicator bacteria in local receiving waters have dropped substantially.

Literature Cited

[APHA] American Public Health Association. (1998). Standard Methods for the Examination of Water and Wastewater, 18th edition. A.E. Greenberg, L.S. Clesceri, and A.D. Eaton (eds.). American

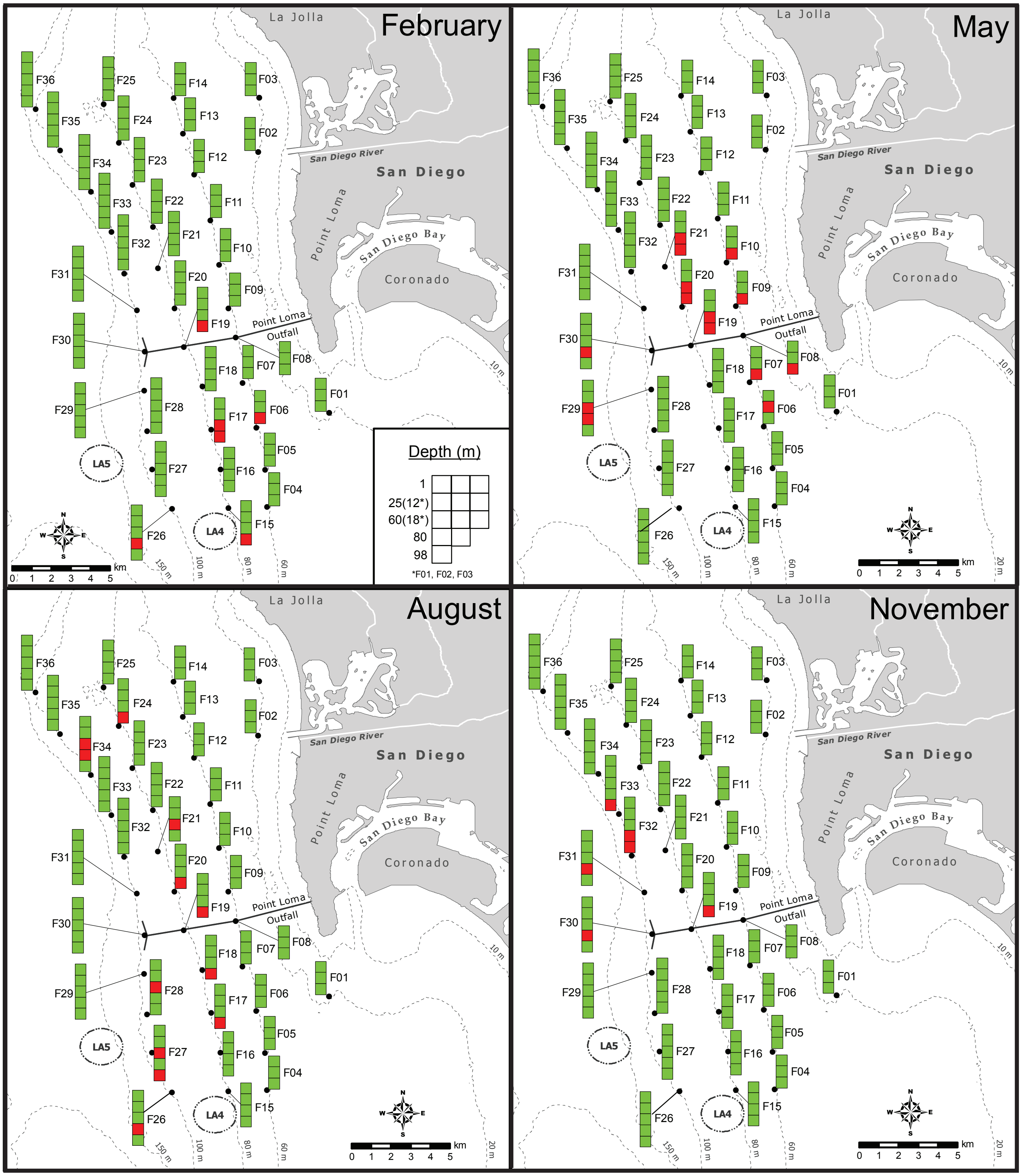


Figure 3.3

Distribution of seawater samples collected during the PLOO quarterly surveys in 2009 that exceeded (red squares) or did not exceed (green squares) the FTR criterion indicative of contaminanted waters. See text and Appendix A.1 for sampling details.

Public Health Association, American Water Works Association, and Water Pollution Control Federation.

Arvanitidou, M., V. Katsouyannopoulos, and A. Tsakris. (2001). Antibiotic resistance patterns of enterococci isolated from coastal bathing waters. Journal of Medical Microbiology, 50: 1001–1005.

Bordner, R., J. Winter, and P. Scarpino, eds. (1978). Microbiological Methods for Monitoring the Environment: Water and Wastes, EPA Research and Development, EPA-600/8-78-017.

[CDHS] California State Department of Health Services. (2000). Regulations for Public Beaches and Ocean Water-Contact Sports Areas. Appendix A: Assembly Bill 411, Statutes of 1997, Chapter 765. http://www.dhs.ca.gov/ps/ddwem/beaches/ab411_regulations.htm.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009a). Monthly Receiving Waters Monitoring Reports for the Point Loma Ocean Outfall, January–November 2009. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009b). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010a). Monthly Receiving Waters Monitoring Reports for the Point Loma Ocean Outfall, December 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010b). EMTS Division Laboratory Quality Assurance Report, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Grant, S., B. Sanders, A. Boehm, J. Redman, R. Kim, A. Chu, M. Gouldin, C. McGee, N. Gardiner, B. Jones, J. Svejkovsky, G. Leipzig. (2001). Generation of enterococci bacteria in a costal saltwater marsh and its impact on surf zone water quality. Environmental Science Technology, 35: 2407–2416.

Griffith, J., K. Schiff, G. Lyon, and J. Fuhrman. (2010). Microbiological water quality at non-human influenced reference beaches in southern California during wet weather. Marine Pollution Bulletin, 60: 500–508.

Martin, A. and S. Gruber. (2005). Amplification of indicator bacteria in organic debris on southern California beaches. Technical Paper 0507. Weston Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005.

Oshiro, R. and R. Fujioka. (1995). Sand, soil and pigeon droppings: sources of indicator bacteria in the waters of Hanauma Bay, Oahu, Hawaii. Water Science Technology, 31: 251–254.

Parnell, E., and L. Rasmussen. (2010). Summary of PLOO hydrographic observations (2006–2009). Draft report to City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Svejkovsky, J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2007–31 December, 2007. Ocean Imaging, Solana Beach, CA.

[SWRCB] California State Water Resources Control Board. (2001). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.

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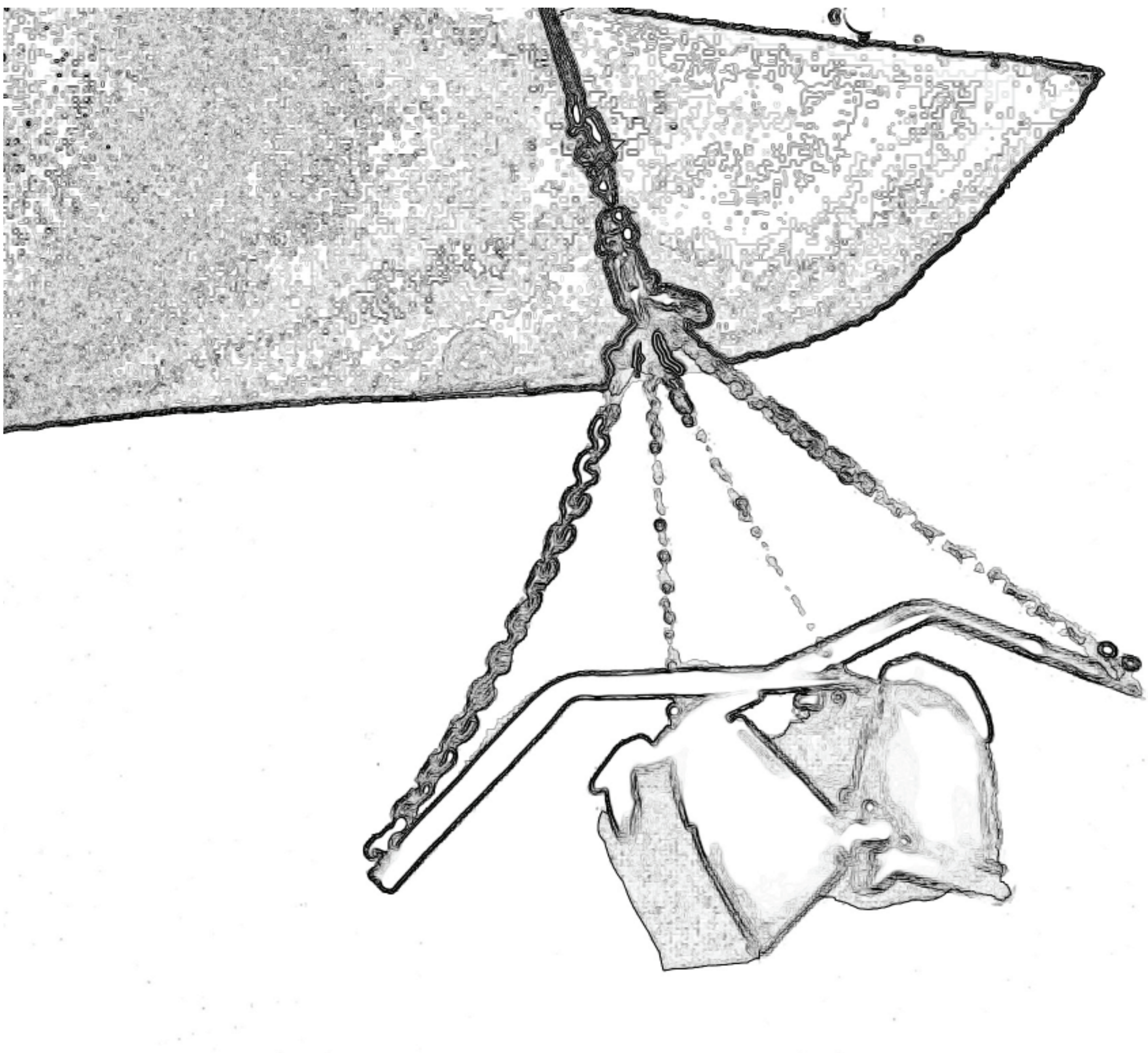
Chapter 4
Sediment Characteristics



Chapter 4. Sediment Characteristics

INTRODUCTION

Ocean sediment samples are collected and analyzed as part of the Point Loma Ocean Outfall (PLOO) monitoring program to characterize the surrounding physical environment and assess general sediment conditions. These conditions define the primary microhabitats for benthic invertebrates that live within or on the surface of sediments, and can therefore influence the distribution and presence of various species. The distributions of many demersal fishes are also often associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Consequently, an understanding of differences in sediment conditions over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, distribution, and stability of seafloor sediments. Natural factors that affect sediment conditions on the continental shelf include the strength and direction of bottom currents, exposure to wave action, seafloor topography, inputs associated with outflows from rivers and bays, beach erosion, runoff from other terrestrial sources, bioturbation by benthic macrofauna, and decomposition of calcareous organisms (e.g., Emery 1960). The analysis of parameters such as sediment grain size and the relative percentages of different sediment fractions (e.g., sand, silt, and clay) can provide useful information about current velocity, amount of wave action and overall habitat stability in an area. Further, understanding sediment particle size distributions facilitates interpretation of the interactions between benthic organisms and the environment. For example, differences in sediment composition (e.g., fine vs. coarse particles) and associated levels of organic loading at specific sites can affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Geological history can also affect the chemical composition of local sediments. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediments and debris from bays, rivers, and streams can contribute to the deposition and accumulation of metals or other contaminants and also affect the overall organic content of sediments. Additionally, primary productivity by phytoplankton is a major source of organics to these sediments (Mann 1982, Parsons et al. 1990). Finally, particle size composition can affect concentrations of chemical constituents within sediments. For example, levels of organic compounds and trace metals within ocean sediments generally rise with increasing amounts of fine particles (Emery 1960, Eganhouse and Venkatesan 1993).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence the composition and distribution of sediments through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected compounds discharged via ocean outfalls are trace metals, pesticides, and various organic compounds such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). Moreover, the presence of large outfall pipes and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas.

This chapter presents summaries and analyses of sediment grain size and chemistry data collected during 2009 at monitoring sites surrounding the PLOO. The primary goals are to: (1) assess possible effects of wastewater discharge on benthic habitats by analyzing spatial and temporal variability of various sediment parameters, (2) determine the presence or absence of sedimentary and chemical footprints near the discharge site, and (3) evaluate overall sediment quality in the region.

Materials and Methods

Field Sampling

Sediment samples were collected at 22 benthic stations in the PLOO region during 2009 (Figure 4.1). These stations are located along the 88, 98, and 116-m depth contours, and include "E" stations located within 8 km of the outfall, and "B" stations located greater than 11 km north of the outfall. During 2009, the January survey was limited to 12 "primary core" stations along the 98-m depth contour to accommodate additional sampling for the Bight'08 regional project (see Chapter 1), while the July survey included all 22 stations. The four stations considered to represent "nearfield" conditions herein (i.e., E11, E14, E15, E17) are located between about 100–750 m of the center of the outfall wye or the ends of the diffuser legs. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis and visual observations of sediment composition (see Chapter 5). Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to EPA guidelines (U.S. EPA 1987).

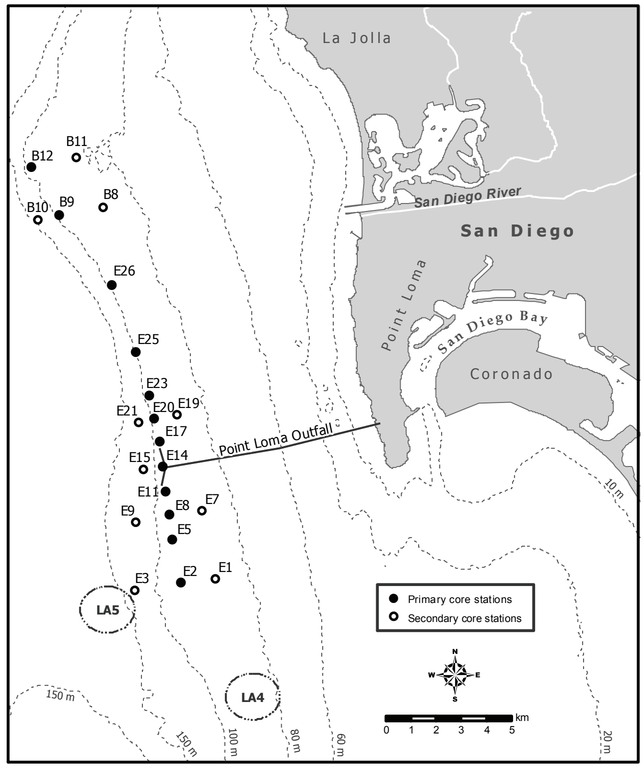


Figure 4.1
Benthic station locations sampled for the Point Loma Ocean Outfall Monitoring Program.

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. The Horiba analyzer measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Coarser sediments from these samples were removed prior to laser analysis by screening the samples through a 2.0-mm mesh sieve. These data were expressed as "percent coarse" of the total sample sieved, and later combined with the Horiba results to obtain a complete distribution of particle sizes (see below). When a sample contained substantial amounts of coarse materials (e.g., coarse sand, gravel, shell hash) which would damage the Horiba analyzer and/or where the general distribution of sediment sizes would be poorly represented by laser analysis, a set of six nested sieves was instead used to separate the grain size fractions. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2009, 32 samples were processed by laser analysis and two samples (stations E2 and E14 during July) were processed by sieve analysis. Results from sieve analysis and output from the Horiba were categorized into sand, silt, and clay fractions as follows: sand was defined as particles ranging between 2.0 and >0.0625 mm in diameter, silt as particles between 0.0625 and >0.0039 mm, and clay as particles between 0.0039 and >0.00049 mm. These data were standardized and combined with any sieved coarse fraction (i.e., particles >2.0 mm) to obtain a complete distribution of the coarse, sand, silt, and clay fractions totaling 100%. These four size fractions were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1968). Summaries of particle size parameters included overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was chemically analyzed to determine concentrations of total organic carbon (TOC), total nitrogen (TN), total sulfides, biochemical oxygen demand (BOD), total volatile solids (TVS), trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.1). TOC, TN, and TVS were measured as percent weight (% wt) of the sediment sample; BOD, sulfides, and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and are expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and are expressed as parts per billion (ppb). Reported values were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A detailed description of the analytical protocols is available in City of San Diego (2010).

Data Analyses

Data summaries for the various sediment parameters measured during 2009 included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total chlordane, total DDT, total PCB, and total PAH were calculated for each sample as the sum of all constituents with reported values (see Appendix C.2 for individual constituent values). Statistical analyses included Spearman Rank correlation of the percent of fine sediments (% fines) with each chemical parameter. This non-parametric analysis accommodates non-detects (i.e., analyte concentrations measured below the MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (see Conover 1980). Therefore, a criterion of < 50% non-detects was used to screen eligible constituents for this analysis. In addition, only parameters analyzed with a single MDL throughout the entire year were considered for correlation analysis (see Helsel 2005). Correlation results were confirmed visually by graphical analyses.

Data from the 2009 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally established the ERLs and ERMs to provide a means for interpreting environmental monitoring data. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Contamination levels were further evaluated by comparing results for the current year with historical data, including comparisons between the maximum values for 2009 to those from the pre-discharge period (i.e., 1991–1993). In addition, data for percent fines and organic indicators from the nearfield stations were compared to data from the northern reference stations, as well as stations between 1–8 km to the north and south of the outfall, over the pre-and post-discharge periods.

Results and Discussion

Particle Size Distribution

During 2009, ocean sediments collected off Point Loma were composed predominantly of coarse silt and very fine sands, with mean particle sizes ranging from about 0.04 to 0.12 mm (Table 4.1).

Table 4.1

Summary of particle size and sediment chemistry parameters at PLOO benthic stations during 2009. Data include the detection rate (DR), areal mean of detected values, and minimum (Min), median, and maximum (Max) values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1991–1993) is also presented. ERL = effects range low threshold; ERM = effects range median threshold; na = not available; nd = not detected; SD = standard deviation; BOD = biochemical oxygen demand; TN = total nitrogen; TOC = total organic carbon; TVS = total volatile solids.

	2009 Summary*					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL**	**ERM**
Particle Size								
Mean (mm)	**	0.06	0.04	0.06	0.12	0.18	na	na
Mean (phi)	**	4.1	3.1	4.1	4.6	5.8	na	na
SD (phi)	**	1.5	0.7	1.5	1.9	3.0	na	na
Coarse (%)	**	0.8	0.0	0.0	9.3	26.4	na	na
Sand (%)	**	61.2	43.2	62.2	72.1	79.3	na	na
Fines (%)	**	38.0	27.9	37.2	56.8	74.2	na	na
Organic Indicators								
BOD (% weight)	97	270	nd	238	>535	656	na	na
Sulfides (ppm)***	97	3.35	nd	1.35	33.90	20.00	na	na
TN (% weight)	100	0.051	0.030	0.051	0.087	0.074	na	na
TOC (% weight)	100	1.02	0.46	0.69	4.27	1.57	na	na
TVS (% weight)	100	2.45	1.67	2.25	5.42	5.00	na	na
Trace Metals (ppm)								
Aluminum	100	7504	3130	7660	11,300	na	na	na
Antimony	12	0.4	nd	nd	0.4	6.0	na	na
Arsenic	100	3.14	1.49	2.78	7.27	5.56	8.2	70
Barium	100	35.3	10.3	33.8	58.8	na	na	na
Beryllium	65	0.23	nd	0.19	0.34	2.01	na	na
Cadmium	94	0.13	nd	0.12	0.18	6.80	1.2	9.6
Chromium	100	15.9	7.4	15.7	23.6	51.0	81	370
Copper	100	6.5	1.5	6.2	11.7	34.0	34	270
Iron	100	11,869	5570	11,300	17,900	26,000	na	na
Lead	100	4.5	2.1	4.0	13.2	18.0	46.7	218
Manganese	100	83.3	35.9	85.8	114.0	na	na	na
Mercury	100	0.028	0.009	0.024	0.065	0.096	0.15	0.71
Nickel	100	6.8	3.1	6.8	9.1	14.0	20.9	51.6
Selenium	6	0.25	nd	nd	0.25	0.90	na	na
Silver	0	—	nd	nd	nd	7.00	1	3.7
Thallium	0	—	nd	nd	nd	152.0	na	na
Tin	91	0.8	nd	0.9	1.3	na	na	na
Zinc	100	29.4	14.3	28.7	47.8	67.0	150	410
Pesticides (ppt)								
Chlordane	6	650	nd	nd	950	nd	na	na
tDDT	71	507	nd	335	1120	8800	1580	46,100
Endrin aldehyde	3	970	nd	nd	970	nd	na	na
HCB	32	377	nd	nd	1600	nd	na	na
Total PCB (ppt)	50	3126	nd	nd	22,315	na	na	na
Total PAH (ppb)	9	174	nd	nd	312	199	4022	44,792

* Minimum, maximum, and median values were calculated based on all samples ($n = 34$), whereas means were calculated on detected values only ($n \leq 34$).

** Particle size parameters calculated for all samples.

*** Sulfide samples for stations B9 and B12 in the January survey held over time limit; results not reportable.

There was little difference in intra-station particle size composition between the January and July surveys. The greatest difference occurred at station E2, where percent fines varied from 43% in January to 35% in July, with the average particle size increasing by about 0.06 mm (Appendix C.3). Overall, percent fines averaged 38% across the region during the year, ranging from a low of 28% to a high of 57% (Figure 4.2). No major changes in percent fines composition of PLOO sediments have occurred since the initiation of wastewater discharge at the end of 1993 (Figure 4.3). However, there has been a slight decrease in percent fines and a corresponding increase in mean particle size at station E14 located nearest the discharge site (see City of San Diego 2007). This increase may be due in part to the presence of ballast or bedding material around the outfall.

The sorting coefficient reflects the range of grain sizes in a sample and is calculated as the standard deviation (SD) in phi size units (see Table 4.1). In general, sediments composed of particles of similar size with a SD $\leq$0.5 phi are considered to be well-sorted and indicative of areas subject to fast moving currents or large disturbances (Folk 1968). In contrast, samples with particles of varied sizes with a SD $\geq$1.0 phi are characteristic of poorly sorted sediments. Most stations sampled in the Point Loma region in 2009 had poorly sorted sediments with sorting coefficients ranging from a low of 1.3 phi in January to a high of 1.9 phi in July (Appendix C.3). These results are typical of mid-shelf habitats and reflect the multiple origins of sediments in the region (see Emery 1960). This also suggests that these sites are not subject to fast moving currents or large physical disturbances. The main exception to this pattern occurred at station E14 in July, where sediments were moderately well sorted (i.e., SD = 0.7), and there was a higher percentage of coarse materials (8%) than at most other sites (see Appendix C.3). Visual observations of the sediments collected with this grab sample indicated the presence of coarse black sand and rocks, possibly related to ballast and bedding material for the outfall.

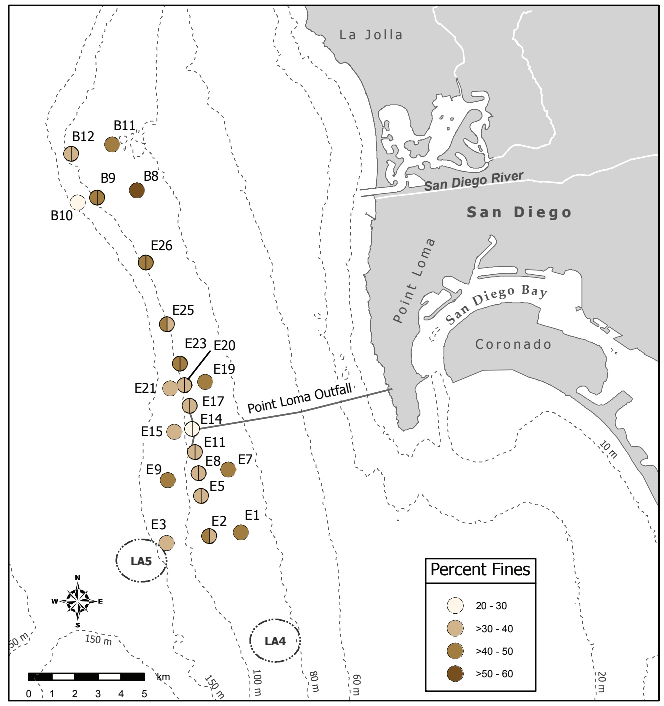


Figure 4.2
Distribution of fine sediments (percent fines) at PLOO benthic stations sampled during 2009. Only primary core stations were sampled in January; all stations were sampled in July (see text); split circles show results of January (left) and July (right) surveys.

Indicators of Organic Loading

Total organic carbon (TOC), total nitrogen (TN), total volatile solids (TVS), biochemical oxygen demand (BOD), and sulfides were quantified in sediments at the PLOO stations as potential measures of organic loading. The distribution of organic indicators in the region during 2009 was generally similar to that seen prior to wastewater discharge (see City of San Diego 1995). TOC, TN and TVS were detected in 100% of sediment samples, while BOD occurred in 97% of the samples (Table 4.1). Sulfides were also detected about 97% of the time, although results for the January samples from stations B9 and B12 were not reportable as they exceeded holding time limits. The highest concentrations of most organic indicators tended to occur at stations north of the outfall, including the reference "B" stations located almost 10 km or more from the end of the northern diffuser leg (see Appendix C.4). The main

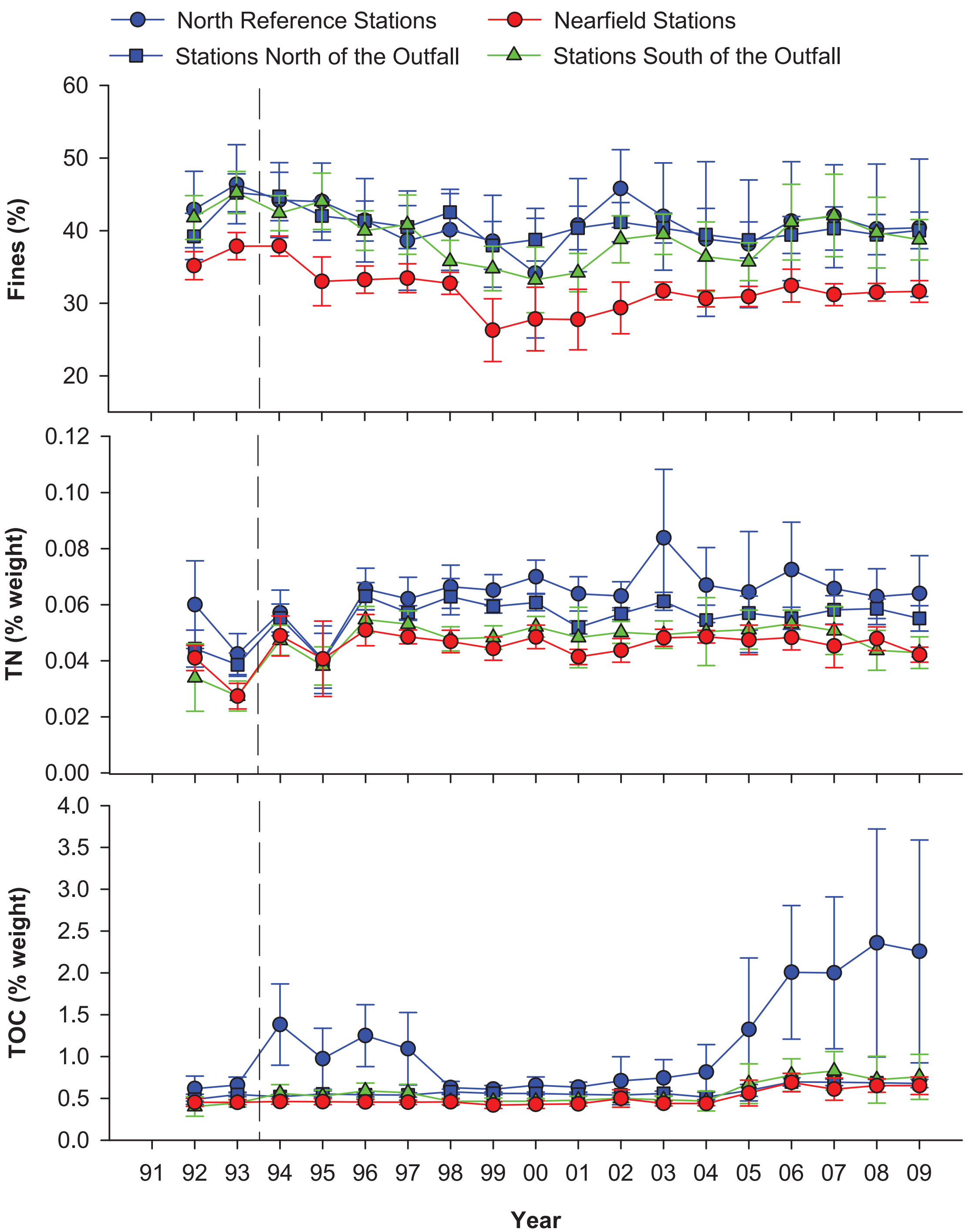


Figure 4.3

Summary of particle size and organic indicator data surrounding the PLOO from 1991–2009: Percent fines (Fines); Total Nitrogen (TN); Total Organic Carbon (TOC); Sulfides; Biochemical Oxygen Demand (BOD); Total Volatile Solids (TVS). Data are expressed as means pooled over all stations in each station group (North Reference = B8–B12; North of the Outfall = E19–E21, E23, E25, E26; Nearfield = E11, E14, E15, E17; South of the Outfall = E1–E3, E5, E7–E9); Error bars represent 95% confidence limits. Dashed lines indicate onset of discharge from the PLOO.

exceptions to this pattern were values for sulfides, which were highest at near-ZID station E14 during both surveys. In general, only sulfides, and to a lesser extent BOD, have shown changes near the outfall that appear to be associated with organic enrichment (see Figure 4.3; see City of San Diego 2007). Lastly, there was no correlation between sediment concentrations of organic indicators with the proportion of fine material within a sample ($r_s < 0.55$).

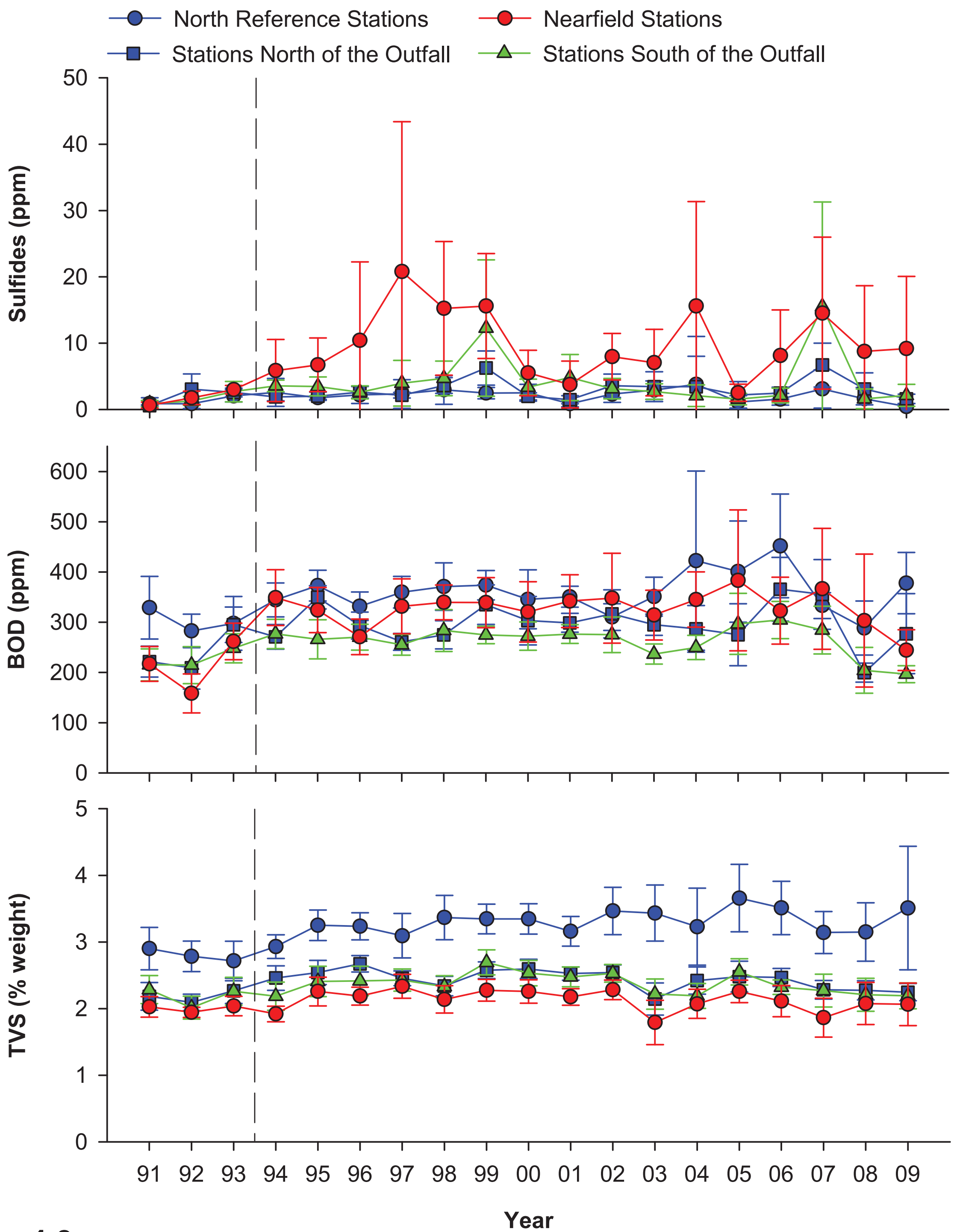


Figure 4.3 *continued*

Trace Metals

Detectable levels of aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc occurred in all of the sediment samples collected in the Point Loma region during 2009 (Table 4.1). Another five metals (i.e., antimony, beryllium, cadmium, selenium, tin) were detected less frequently at rates of 6–94%, while silver and thallium were not detected at all. Metal concentrations were variable, and there were no discernable spatial patterns relative to the outfall. Instead, concentrations of four metals (i.e., barium, copper, manganese, nickel) were positively correlated with the proportion of fine

Table 4.2

Results of Spearman Rank correlation analyses of percent fine material with sediment chemistry parameters from PLOO benthic samples collected in 2009. Shown are analytes which had correlation coefficients (r_s) ≥ 0.60. For all analyses, $p < 0.001$. A representative correlation is illustrated graphically in Figure 4.4 below.

Analyte	r_s
Trace Metals (ppm)	
Barium	0.69
Copper	0.60
Manganese	0.66
Nickel	0.68

particles in the sample (Table 4.2, Figure 4.4). In addition, the highest metal concentrations tended to occur in sediments from the north reference stations and/or stations located south of the outfall. For example, the highest concentrations of arsenic, beryllium, cadmium, chromium, and iron were detected in sediments collected from station B12 located farthest to the north (Appendix C.5). In contrast, the highest concentration of lead (13.2 ppm) occurred in sediments collected at station E14 in January. Overall, concentrations of the different trace metals were generally low in the region, with most values reported for 2009 being below the highest concentrations detected prior to wastewater discharge (e.g., see Appendix C.5). Finally, no samples collected during the year had metal concentrations that exceeded either the ERL or ERM sediment quality guidelines.

Pesticides

Chlorinated pesticides were detected in up to 71% of the samples collected from PLOO stations in 2009 (Table 4.1). Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring in sediments from all but one station with an overall mean concentration of 507 ppt. Concentrations of this pesticide ranged from a low of 150 ppt to a high of 1120 ppt, the latter of which is still below both the ERL (1580 ppt) and maximum pre-discharge value (8800 ppt) for DDT (Appendix C.6). Another pesticide, hexachlorobenzene (HCB), was detected in 32% of the sediment samples at concentrations ranging from 67 to 1600 ppt. HCB occurred at two of the northern reference stations during January and at nine other sites throughout the region in July, the latter including nearfield station E11. The maximum concentration of HCB was detected at station E2, located east of the LA-5 disposal site about 4 km south of the outfall. Two other types of pesticides, chlordanes and endrin aldehyde, were detected for the first time in PLOO sediments since monitoring began, which may be due to recent improvements in analytical techniques for such compounds. However, these two pesticides were detected in low

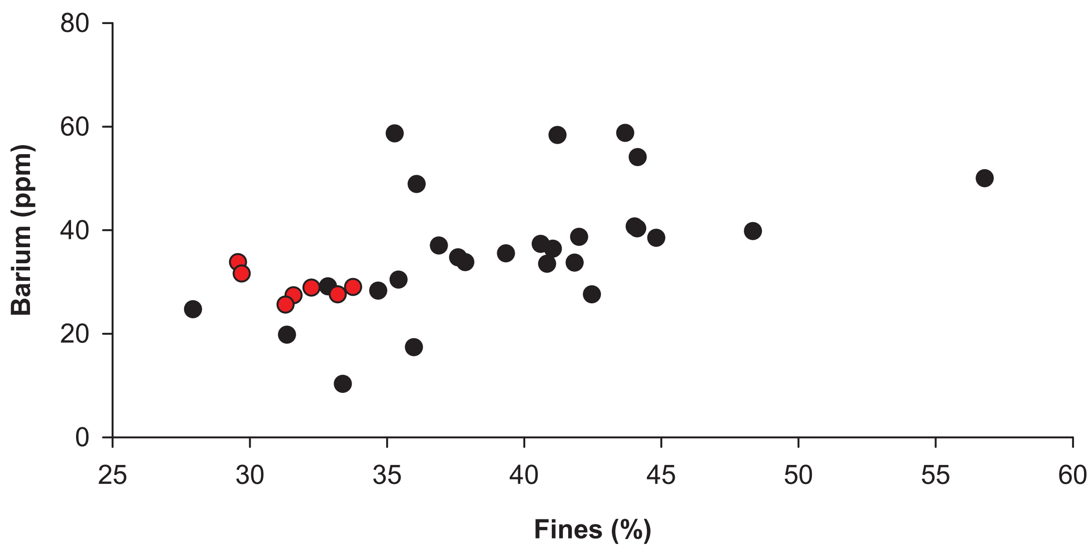


Figure 4.4

Scatterplot of percent fines and concentration of barium in PLOO sediments in 2009. Samples collected from nearfield stations are indicated in red.

concentrations (i.e., near or below the MDL) in a total of only three samples during the July survey. Chlordanes were detected in two sediment samples from stations E1 and E3 located adjacent to or east of the LA-5 disposal site, while endrin aldehyde was detected in a single sample from station E8 located just over 1 km south of the PLOO discharge area. As with the organic indicators and most metals, pesticide concentrations were unrelated to the fine fraction of sediments in a sample ($r_s < 0.44$), and there were no patterns indicative of an outfall effect.

PCBs and PAHs

Polychlorinated biphenyl compounds (PCBs) were detected in 50% of all PLOO sediment samples during 2009 (Table 4.1), most of which were collected from stations south of the outfall (see Appendix C.6). Total PCB concentrations ranged from 71 to 22,315 ppt in the region, with the highest levels occurring at two sites located between the LA-5 disposal site and the mouth of San Diego Bay (i.e., stations E1 and E3), and from one site (station E9) located between LA-5 and the southern leg of the PLOO. Each of these stations also had the highest number of detected PCB congeners (e.g., up to 24/sample) (see Appendix C.2). PCBs have historically occurred at these and other stations located within 2–5 km of LA-5, possibly due to the presence of dredge material dumped short of the intended site (see City of San Diego 2007, Parnell et al. 2008). With the exception of the January sample from station E11, all other detections of PCBs in the region were substantially lower (e.g., < 1300 ppt), and there was no evidence of PCB enrichment surrounding the PLOO.

While PCBs were detected in sediments from several PLOO stations throughout 2009, PAHs occurred at only three sites (i.e., stations E2, E3 and E9) at a detection rate of 9% (Table 4.1). Total PAH concentrations ranged from 95 to 312 ppb (mean = 174 ppb), well below the ERL of 4022 ppb (Appendix C.6). The most prevalent PAHs were 3,4 benzo(B)fluoranthene, benzo[A]anthracene, and chrysene (Appendix C.2), which occurred at all three of the above stations. Overall, there was no apparent relationship between PAH concentrations and proximity to the outfall discharge site.

Summary and Conclusions

Ocean sediments at stations surrounding the PLOO in 2009 were comprised primarily of fine sands and coarse silt. Most of these sediments were poorly sorted, consisting of particles of varied sizes, which suggest that sediments in the region were subject to low wave and current activity and/or physical disturbance. The moderately well sorted sample collected at station E14 in July was an exception, consisting of mostly fine sands, with some coarser materials which may have originated as ballast or bedding material for the outfall structure. Overall, variability in the particle size composition of sediments in the PLOO region is likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geological origins of different sediment types, and recent deposition of detrital materials (e.g., Emery 1960, City of San Diego 2007, Parnell et al. 2008). The PLOO lies within the Mission Bay littoral cell, with natural sources of sediments including outflows from Mission Bay and the San Diego River (Patsch and Griggs 2006), as well as from San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (Farnsworth and Warrick 2007), thus widening the range of potential sediment sources to the region.

Concentrations of various contaminants, including most indicators of organic loading (e.g., BOD, TN, TVS), trace metals, pesticides (e.g., DDT), PCBs, and PAHs in sediments off Point Loma remained within the typical range observed for San Diego and other areas of the southern California continental shelf (see Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006). Low concentrations of chlordanes and endrin aldehyde were detected in PLOO sediments for the first time since monitoring began, although these pesticides occurred in only three samples from stations located south of the outfall. Likewise, PAHs were only rarely detected (i.e., 9% of samples). Although DDT was present in sediments at most stations, all concentrations were below thresholds of biological concern. Overall, there were no contaminants that exceeded the ERL or ERM thresholds in PLOO sediments in 2009.

There were no clear spatial patterns in sediment contaminants relative to the PLOO discharge site in 2009, with the exception of slightly elevated sulfide and BOD levels near the outfall as described in previous years (e.g., City of San Diego 2007). Instead, the highest concentrations of several organic indicators, metals, pesticides, PCBs, and PAHs were found in sediments from both the southern and/or northern-most stations. Historically, concentrations of contaminants have been higher in sediments at most of the southern stations (i.e., E1–E3, E5, E7–E9) than elsewhere off San Diego, which may be due in part to short dumps of dredged materials originally destined for LA-5 (see Anderson et al. 1993, City of San Diego 2003, Steinberger et al. 2003, Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 16 years of wastewater discharge. For example, concentrations of most measured parameters continue to occur at levels within the range of variability typical for the San Diego region (e.g., see City of San Diego 2007). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall discharge site (i.e., stations E11, E14 and E17). These effects include a minor increase in sediment particle size through time, measurable increases in sulfide concentrations, and smaller increases in BOD (City of San Diego 2007). However, the data do not suggest that wastewater discharge is affecting the quality of benthic sediments to the point that it will degrade the resident marine biota in the PLOO region (e.g., see Chapters 5 and 6).

Literature Cited

Anderson, J.W., D.J. Reish, R.B. Spies, M.E. Brady, and E.W. Segelhorst. (1993). Human Impacts. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 682–766.

City of San Diego. (1995). Outfall Extension Pre-Construction Monitoring Report (July 1991–October 1992). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). An Ecological Assessment of San Diego Bay: A Component of the Bight'98 Regional Survey. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). 2009 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2ed. John Wiley & Sons, Inc., New York, NY.

Cross, J.N. and L.G. Allen. (1993). Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eganhouse, R.P. and M.I. Venkatesan. (1993). Chemical Oceanography and Geochemistry. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 71–189.

Emery, K.O. (1960). The Sea off Southern California. John Wiley, New York, NY.

Farnsworth, K.L., and J.A. Warrick. (2007). Sources, dispersal, and fate of fine sediment supplied to coastal California. U.S. Geological Survey Scientific Investigations Report 2007–5254.

Folk, R.L. (1968). Petrology of Sedimentary Rocks. Hemphill, Austin, Texas.

Gray, J.S. (1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press, Cambridge, England.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Mann, K.H. (1982). The Ecology of Coastal Marine Waters: A Systems Approach. University of California Press, Berkeley, CA.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Parsons, T.R., M. Takahashi, and B. Hargrave (1990). Biological Oceanographic Processes 3rd Edition. Pergamon Press, Oxford.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Snelgrove, P.V.R. and C.A. Butman. (1994). Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology Annual Review, 32: 111–177.

Steinberger, A., E. Stein, and K. Schiff. (2003). Characteristics of dredged material disposal to the Southern California Bight between 1991 and 1997. In: Southern California Coastal Water Research Project Biennial Report 2001–2002. Long Beach, CA. p 50–60.

[U.S. EPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuary Protection.

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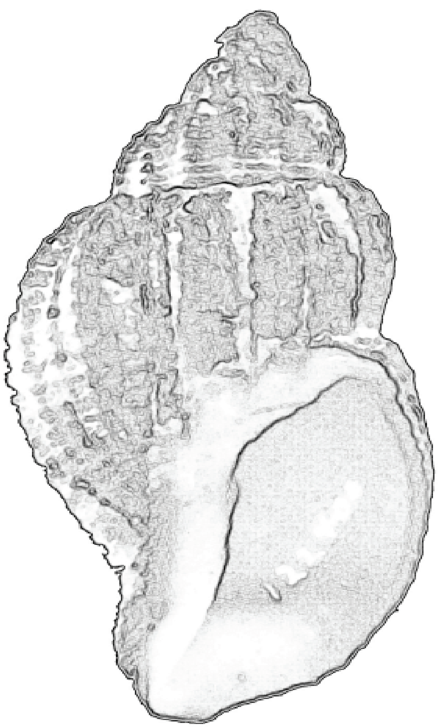
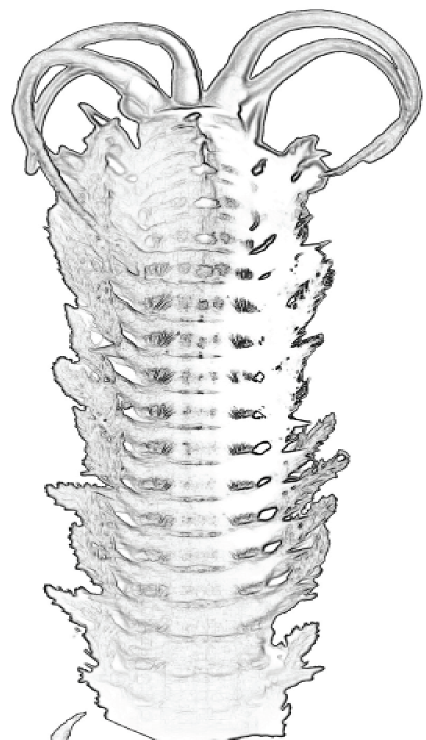
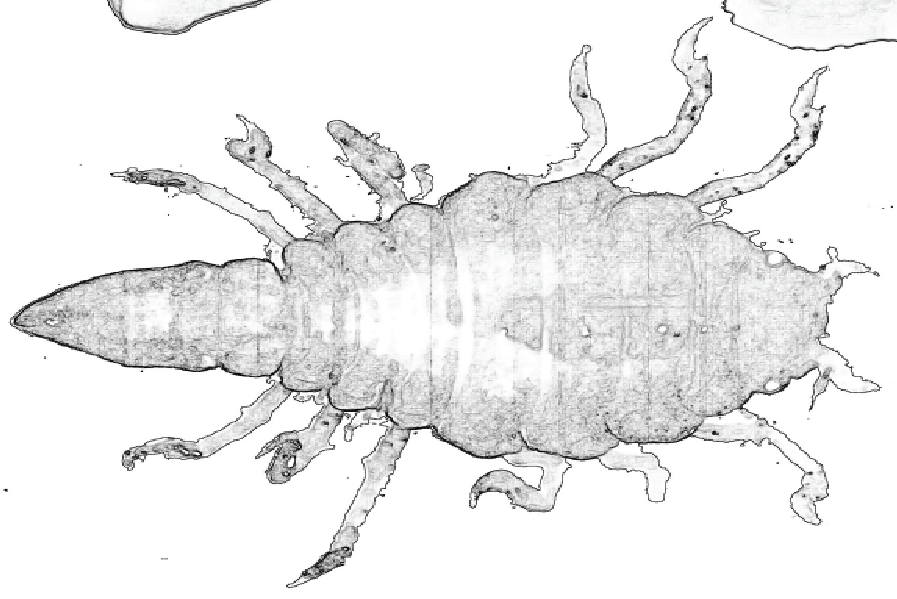
Chapter 5
Macrobenthic Communities







Chapter 5. Macrobenthic Communities

INTRODUCTION

Benthic macroinvertebrates along the coastal shelf of southern California represent a diverse faunal community that is important to the marine ecosystem (Fauchald and Jones 1979, Thompson et al. 1993a, Bergen et al. 2001). These animals serve vital ecological functions in wide ranging capacities (Snelgrove et al. 1997). For example, some species decompose organic material as a crucial step in nutrient cycling; other species filter suspended particles from the water column, thus affecting water clarity. Many species of benthic macrofauna also are essential prey for fish and other organisms.

Human activities that impact the benthos can sometimes result in toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation. Certain macrofaunal species are sensitive to such changes and rarely occur in impacted areas, while others are opportunistic and can persist under altered conditions (Gray 1979). Because various species respond differently to environmental stress, monitoring macrobenthic assemblages can help to identify anthropogenic impact (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). Also, since many animals in these assemblages are relatively stationary and long-lived, they can integrate the effects of local environmental stressors (e.g., pollution or disturbance) over time (Hartley 1982, Bilyard 1987). Consequently, the assessment of benthic community structure is a major component of many marine monitoring programs, which are often designed to document both existing conditions and trends over time.

Overall, the structure of benthic communities may be influenced by many factors including depth, sediment composition and quality (e.g., grain size distribution, contaminant concentrations), oceanographic conditions (e.g., temperature, salinity, dissolved oxygen, ocean currents), and biological factors (e.g., food availability, competition, predation). For example, benthic assemblages on the coastal shelf of southern California typically vary along sediment particle size and/or depth gradients (Bergen et al. 2001). Therefore, in order to determine whether changes in community structure are related to human impacts, it is necessary to have an understanding of background or reference conditions for an area. Such information is available for the monitoring area surrounding the Point Loma Ocean Outfall (PLOO) and the San Diego region in general (e.g., see City of San Diego 1999, 2010; Ranasinghe et al. 2003, 2007).

This chapter presents analyses and interpretations of the macrofaunal data collected at fixed stations surrounding the PLOO during 2009. Descriptions and comparisons of the different macrofaunal assemblages that inhabit soft bottom habitats in the region and analysis of benthic community structure are included.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected at 22 benthic stations in the PLOO region located along the 88, 98, or 116-m depth contours (Figure 5.1). These sites included 17 “E” stations located from approximately 5 km south to 8 km north of the outfall, and five “B” stations located about 11 km or further north of the outfall. During 2009, the January survey was limited to 12 “primary core” stations along the 98-m depth contour to accommodate additional sampling for the Bight’08 regional project (see Chapter 1), while the July survey included all 22 stations. Four stations considered to represent “nearfield” conditions herein (i.e., E11, E14, E15, E17) are located between about 100 and 750 m of the outfall wye or diffuser legs.

Two replicate samples for benthic community analyses were collected per station during each survey using a double 0.1-m^2 Van Veen grab. One

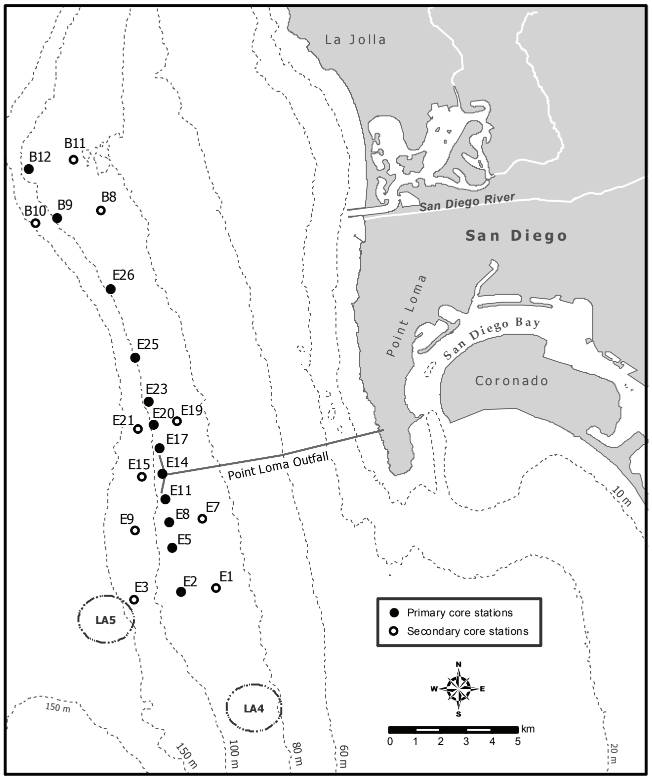


Figure 5.1
Benthic station locations sampled for the Point Loma Ocean Outfall Monitoring Program.

of the two grabs from the first cast was used for macrofauna, while the adjacent grab was used for sediment quality analysis (see Chapter 4); a second grab for macrofauna was then collected from a subsequent cast. Criteria established by the EPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (U.S. EPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen. Organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontractor, and then identified to species (or the lowest taxon possible) and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), benthic response index (BRI; see Smith et al. 2001), and infaunal trophic index (ITI; see Word 1980). Additionally, the total or cumulative number of species over all grabs was calculated for each station.

Multivariate analyses were performed using PRIMER software to examine spatio-temporal patterns in the overall similarity of benthic assemblages in the region (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (MDS). Macrofaunal abundance data were square-root transformed and the Bray-Curtis measure of similarity was used as the basis for classification. Similarity profile analysis (SIMPROF) was used to confirm non-random structure of the dendrogram (Clarke et al. 2008), while the 'similarity percentages' routine (SIMPER) was used to identify species that typified each cluster group.

A BACIP (Before-After-Control-Impact-Paired) statistical model was used to test the null hypothesis that there have been no changes in select community parameters due to operation of the PLOO (see Bernstein and Zalinski 1983, Stewart-Oaten et al. 1986, 1992; Osenberg et al. 1994). The BACIP model compares differences between control (reference) and impact sites at times before (i.e., July 1991–October 1993) and after (i.e., January 1994–July 2009) an impact event (i.e., the onset of discharge). The analyses presented in this report are based on 2.5 years (10 quarterly surveys) of before impact data and 16 years (51 quarterly or semi-annual surveys) of after impact data. The E stations, located between about 0.1 and 8 km of the outfall, are considered most likely to be affected by wastewater discharge (Smith and Riege 1994). Station E14 was selected as the impact site for all analyses; this station is located near the boundary of the Zone of Initial Dilution (ZID) and probably is the site most susceptible to impact.

In contrast, the B stations are located farther from the outfall (>11 km) and are the obvious candidates for reference or control sites. However, benthic communities differed between the B and E stations prior to discharge (Smith and Riege 1994, City of San Diego 1995). Thus, two stations (E26 and B9) were selected to represent separate control sites in the BACIP tests. Station E26 is located 8 km north of the outfall and is considered the E station least likely to be impacted. Previous analyses suggested that station B9 was one of the most appropriate B stations for comparison with the E stations (Smith and Riege 1994, City of San Diego 1995). Six dependent variables were analyzed, including three community parameters (number of species, infaunal abundance, BRI) and abundances of three taxa that are considered sensitive to organic enrichment. These indicator taxa include ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using one-tailed paired t-tests with a type I error rate of $\alpha = 0.05$.

Results and Discussion

Community Parameters

Species richness

A total of 483 macrofaunal taxa (mostly species) were identified during the 2009 PLOO surveys. Approximately 24% ($n = 117$) of these were rare species or unidentifiable taxa (e.g., juveniles or damaged specimens) that occurred only once. Mean species richness values (no. species/0.1 m^2) ranged from 76 species at station B8 to 124 species at station E9 (Table 5.1). Average values for the other 20 sites sampled during the year ranged between 77 and 105 taxa per grab. Overall, the average species richness among the 12 primary core stations increased about 10% since 2008 (e.g., see City of San Diego 2009).

Macrofaunal abundance

A total of 21,721 macrofaunal individuals were counted in 2009 with mean abundance values ranging from 234 to 518 animals per 0.1-m^2 sample (Table 5.1). The largest number of animals occurred at station E9, which was the only station to average more than 500 animals per grab. The fewest animals (mean = 234/grab) were collected at station E8, while the remaining sites had abundances averaging between 254 and 412 animals per grab. Overall, there was a 25% increase in macrofaunal abundance collected at the 12 primary core stations between 2008 and 2009, with the largest difference occurring at station E14 (e.g., see City of San Diego 2009). This near-ZID site averaged 237 and 412 individuals per grab in 2008 and 2009, respectively.

Species diversity, evenness, and dominance

Diversity index values (H') averaged from 3.2 to 4.2 at the PLOO stations during 2009 (Table 5.1), which was generally similar to that seen in previous years (e.g., City of San Diego 1995, 2009). The lowest diversity (H' ≤ 3.3) continued to occur at stations E1 and B8, while the remaining stations had mean H' values ≥ 3.7. There were no apparent patterns relative to distance from the outfall discharge site. Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed (i.e., not dominated by a few highly abundant species). During 2009, J' values averaged between 0.71 and 0.92 per station, with spatial patterns similar to those for diversity.

Dominance was expressed as the Swartz dominance index, which is calculated as the minimum number of species whose combined abundance accounts for 75% of the individuals in a sample (Swartz et al. 1986, Ferraro et al. 1994). Therefore, lower index values (i.e., fewer species) indicate higher numerical dominance. Benthic assemblages in 2009 were characterized by relatively high numbers of evenly distributed species with index values averaging 32 taxa per station (Table 5.1). The highest dominance (index value = 20) was seen at station B8, while the lowest dominance (index value = 41) occurred at station E3. Overall, these results are similar to historical values for the PLOO region (see City of San Diego 2007).

Table 5.1

Summary of macrobenthic community parameters for PLOO stations sampled during 2009. SR = species richness, no. species/0.1 m^2; Tot Spp = cumulative no. species for the year; Abun = abundance, no. individuals/0.1 m^2; H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance, (see text); BRI = benthic response index; ITI = infaunal trophic index. Nearfield stations are in bold. Data are expressed as annual means (n = 4 for primary core stations, n = 2 for all others), except for Tot Spp (n = 1).

	Station	SR	Tot Spp	Abun	H'	J'	Dom	BRI	ITI
88-m Depth Contour	B11	105	149	340	4.1	0.88	40	10	79
	B8	76	111	294	3.3	0.75	20	7	83
	E19	81	111	261	3.7	0.83	30	9	83
	E7	96	131	372	3.9	0.86	33	10	83
	E1	91	128	332	3.2	0.71	28	6	89
*98-m Depth Contour**	B12	92	176	293	4.0	0.90	35	10	77
	B9	94	184	322	3.9	0.87	33	7	82
	E26	89	163	300	3.9	0.87	32	8	79
	E25	92	181	374	3.9	0.86	30	10	79
	E23	84	162	301	3.9	0.89	32	11	80
	E20	86	159	309	4.0	0.89	32	13	77
	E17	**84**	**151**	**327**	**3.9**	**0.87**	**29**	**15**	**75**
	E14	**97**	**203**	**412**	**3.8**	**0.84**	**27**	**20**	**67**
	E11	**87**	**162**	**323**	**3.8**	**0.85**	**28**	**13**	**78**
	E8	77	142	234	3.8	0.88	29	10	81
	E5	87	163	314	3.9	0.88	32	8	82
	E2	89	179	264	3.9	0.86	34	9	84
116-m Depth Contour	B10	98	138	354	4.0	0.86	34	12	78
	E21	97	126	303	4.1	0.89	37	7	85
	E15	**95**	**130**	**290**	**4.0**	**0.89**	**36**	**11**	**85**
	E9	124	177	518	3.9	0.81	36	9	79
	E3	97	144	254	4.2	0.92	41	6	84
All Stations	Mean	90	153	319	3.9	0.86	32	10	79
	Std Error	2	5	10	0.1	0.01	1	1	1
	Min	56	111	157	3.0	0.69	20	4	59
	Max	127	203	610	4.3	0.92	45	22	90

*Primary core stations

Environmental disturbance indices

Benthic response index (BRI) values ranged from 4 to 22 at the various PLOO stations in 2009 (Table 5.1). This indicated that benthic communities in the region are relatively undisturbed as BRI values below 25 are considered indicative of reference conditions (Smith et al. 2001). The highest mean values occurred at station E14 (BRI = 20) located about 120 m west of the center of the outfall wye, stations E11 and E17 (BRI = 13, 15) located within 300 m of the ends of the south and north diffuser legs, respectively, and station E20 (BRI = 13) located about 1.2 km from the end of the northern diffuser leg.

Mean infaunal trophic index (ITI) values ranged from 67 to 89 per station in 2009 (Table 5.1), which is similar to values reported in previous years. These relatively high values (i.e., ITI > 60) have also been considered indicative of undisturbed sediments or reference environmental conditions (see Bascom et al. 1979).

Dominant Species

Macrofaunal communities in the Point Loma region were dominated by polychaete worms in 2009 (Table 5.2). Polychaetes were the most diverse of the major taxa, accounting for 56% of all species collected. Crustaceans accounted for 25% of the species, molluscs 11%, echinoderms 5%, and all other taxa combined for the remaining 3%. Polychaetes were also the most numerous animals, accounting for 56% of the total abundance. Crustaceans accounted for 19% of the animals, molluscs 13%, echinoderms 11%, and the remaining phyla 1%. Overall, the above distributions were similar to those observed in 2008 (see City of San Diego 2009).

Table 5.2

The percent composition of species and abundance by major phyla for PLOO stations sampled during 2009. Data are expressed as annual means (range) for all stations combined; $n=22$.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	56 (47–62)	56 (27–76)
Arthropoda (Crustacea)	25 (18–30)	19 (8–28)
Mollusca	11 (7–17)	13 (4–32)
Echinodermata	5 (3–9)	11 (2–42)
Other Phyla	3 (1–6)	1 (1–3)

Five polychaetes, two molluscs, two arthropods, and one echinoderm were among the 10 most abundant macroinvertebrates sampled during the year (Table 5.3). The most abundant species was the ophiuroid *Amphiodia urtica*, which occurred at 97% of the PLOO stations and averaged 27 individuals per 0.1 m^2. However, since juvenile *A. urtica* usually cannot be identified to species and are recorded as *Amphiodia* sp or Amphiuridae, this number probably underestimates actual populations of this brittle star. Thus, if total *A. urtica* abundance is adjusted to include these unidentified individuals, the estimated density of this species would increase to about 32 brittle stars per grab, similar to that observed in 2008.

Many of the abundant species in 2009 were also dominant prior to discharge and ever since (e.g., City of San Diego 1995, 1999, 2006, 2009). For example, *A. urtica* has been among the most abundant and most commonly occurring species along the outer shelf off Point Loma since sampling began. In contrast, the capitellid *Mediomastus* sp,

Table 5.3

The 10 most abundant macroinvertebrates collected at the PLOO benthic stations sampled during 2009. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Species	Higher Taxa	Percent Occurrence	Abundance per Sample	Abundance per Occurrence
Amphiodia urtica	Echinodermata: Ophiuroidea	97	26.7	27.5
Axinopsida serricata	Mollusca: Bivalvia	97	16.0	16.5
Mediomastus sp	Polychaeta: Capitellidae	100	14.8	14.8
Euphilomedes producta	Arthropoda: Ostracoda	100	11.0	11.0
Polycirrus sp A	Polychaeta: Terebellidae	97	11.0	11.3
Aricidea (*Acmira*) *catherinae*	Polychaeta: Paraonidae	97	10.5	10.9
Chaetozone hartmanae	Polychaeta: Cirratulidae	97	7.1	7.3
Aphelochaeta glandaria complex	Polychaeta: Cirratulidae	94	6.4	6.8
Euphilomedes carcharodonta	Arthropoda: Ostracoda	97	6.0	6.2
Adontorhina cyclia	Mollusca: Bivalvia	74	5.7	7.7

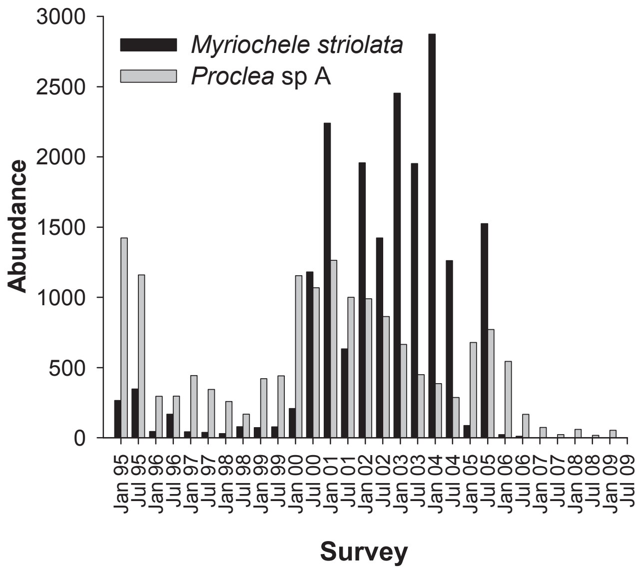


Figure 5.2
Total abundance (no./0.1 m^2) of the polychaetes, *Myriochele striolata* and *Proclea* sp A for each survey at the PLOO benthic stations from 1995–2009.

the third most abundant species collected in 2009, was not widespread until about 2005, after which abundances generally have increased each year (see City of San Diego 1995, 1999, 2006–2009). Other numerically dominant polychaetes in 2009 included the terebellid *Polycirrus* sp A, the paraonid *Aricidea catherinae*, and the cirratulids *Chaetozone hartmanae* and *Aphelochaeta glandaria*. The two most abundant crustaceans were the ostracods *Euphilomedes carcharodonta* and *E. producta*, while the two dominant molluscs were the bivalves *Axinopsida serricata* and *Adontorhina cyclia*.

Densities of other polychaetes such as the oweniid *Myriochele striolata* and the terebellid *Proclea* sp A that have been numerically dominant over time have been more cyclical (Figure 5.2). For instance, both of these species were among the most abundant polychaetes between 1999 and 2005, while their densities have decreased during recent years to levels seen prior to that time. Such variation can have significant effects on other community metrics (e.g., dominance, diversity, and abundance) or environmental indices such as the BRI that use the abundance of specific indicator species in their equations.

Table 5.4
Results of BACIP t-tests for number of species (SR), infaunal abundance, benthic response index (BRI), and the abundance of several representative taxa around the PLOO (1991–2009). Impact site = near-ZID station E14; control sites = farfield station E26 or reference station B9. Before impact period = July 1991 to October 1993 (n = 10); after impact period = January 1994 to July 2009 (n = 51). Critical t-value = 1.680 for α = 0.05 (one-tailed t-tests, df = 59); ns = not significant.

Variable	Control vs Impact	t	*p*
SR	E26 vs E14	-2.89	0.003
	B9 vs E14	-3.27	0.001
Abundance	E26 vs E14	-1.39	ns
	B9 vs E14	-2.64	0.005
BRI	E26 vs E14	-15.50	<0.001
	B9 vs E14	-10.59	<0.001
Ampelisca spp	E26 vs E14	-1.74	0.044
	B9 vs E14	-1.25	ns
Amphiodia spp	E26 vs E14	-6.49	<0.001
	B9 vs E14	-4.62	<0.001
Rhepoxynius spp	E26 vs E14	-0.67	ns
	B9 vs E14	-0.58	ns

BACIP Analyses

BACIP t-tests indicate that there has been a net change in the mean difference of species richness, BRI values, and *Amphiodia* spp abundance between impact site E14 and both control sites since the onset of wastewater discharge from the PLOO (Table 5.4). There also has been a net change in infaunal abundance between E14 and control site B9 as well as a net change in *Ampelisca* spp abundance between E14 and E26. The change in species richness may be due to the increased variability and higher numbers of species at E14 between 1997 and 2007 (Figure 5.3A). Differences in *Amphiodia* populations reflect both a decrease in the number of ophiuroids collected at E14 and a general increase at the control stations through about 2001 (Figure 5.3E). *Amphiodia urtica* densities at station E14 in 2009 were similar to the low densities that have occurred since about 1999. While populations of this brittle star have declined in recent years at both control sites, their densities are more similar to pre-discharge values than near the

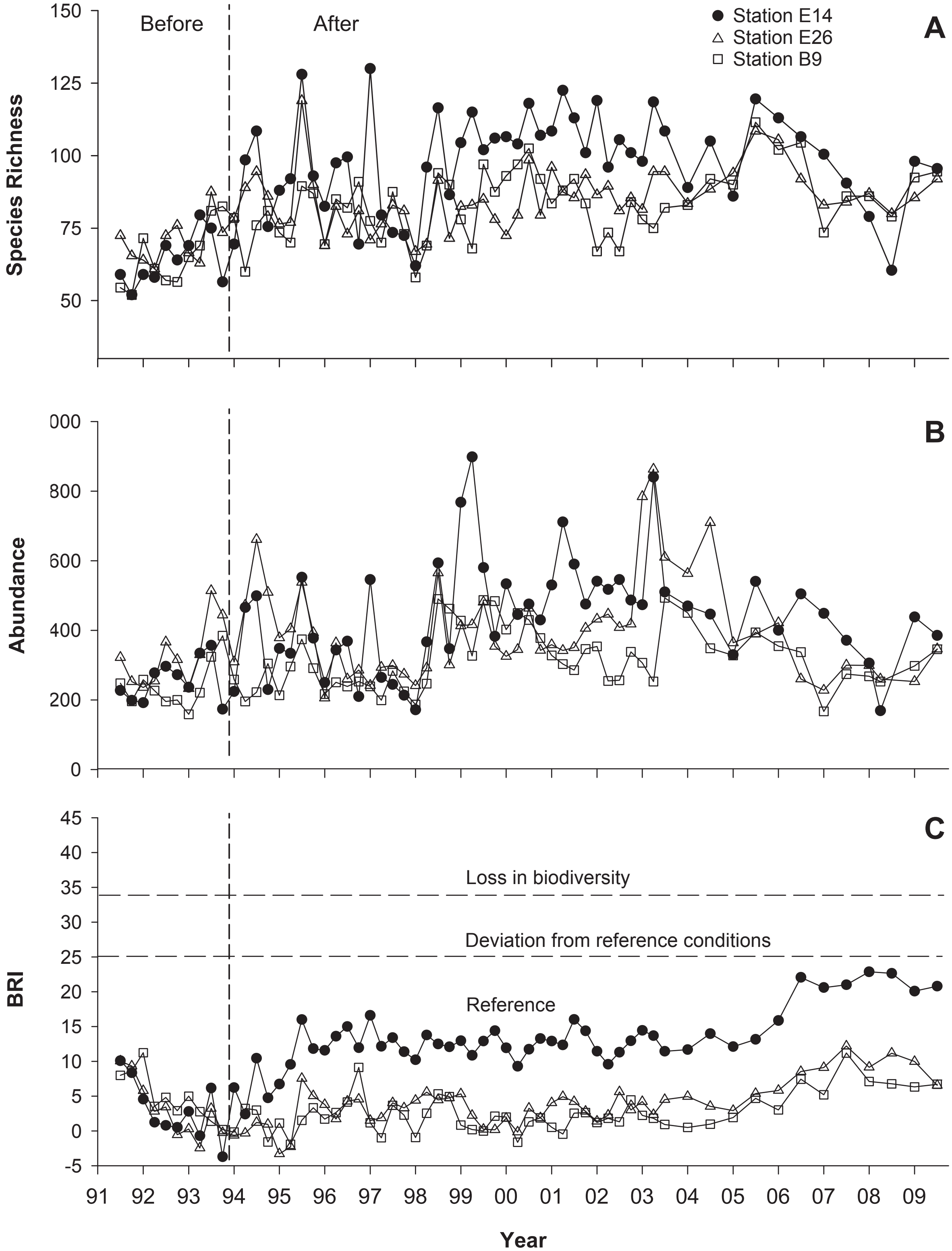


Figure 5.3

Comparison of several parameters at "impact" site (station E14) and "control" sites (stations E26, B9) used in BACIP analyses (see Table 5.4): (A) species richness; (B) infaunal abundance; (C) benthic response index (BRI); (D) abundance of *Ampelisca* spp (Amphipoda); (E) abundance of *Amphiodia* spp (Ophiuroidea). Data for each station are expressed as means per 0.1 m^2 ($n = 2$ per survey).

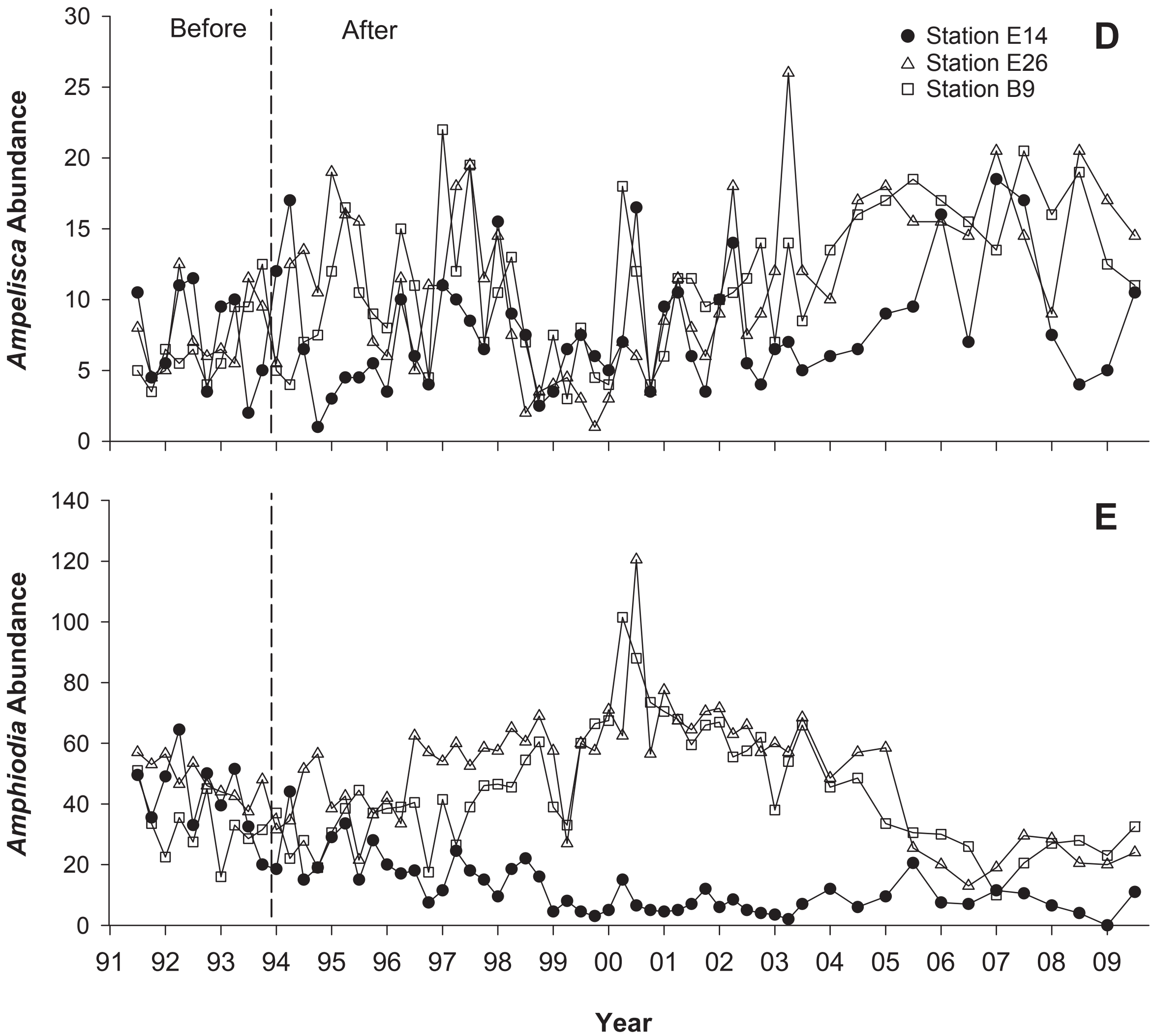


Figure 5.3 *continued*

outfall. Changes in BRI differences generally are due to increased index values at station E14 since 1994 (Figure 5.3C). The higher BRI values at this site may be explained in part by the lower numbers of *Amphiodia*. The BACIP results for total infaunal abundances were more ambiguous (Figure 5.3B, Table 5.3). While the difference in mean abundances between stations B9 and E14 has changed since discharge began, no significant change is apparent regarding the second control site (station E26). No significant changes in the difference in mean abundances of phoxocephalid amphipods (i.e., *Rhepoxynius*) at the impact and control sites have occurred over time (Table 5.4). However, there has been a significant change in the difference in mean abundance of ampeliscid amphipods (i.e., *Ampelisca*) between E14 and E26 (Figure 5.3D, Table 5.4).

Classification of Macrobenthic Assemblages

Results of the ordination and cluster analyses discriminated seven habitat-related macrobenthic assemblages (Figures 5.4 and 5.5). These assemblages, referred to herein as cluster groups A–G, varied in terms of the specific taxa (mostly species) present and the relative abundance of each taxon, and occurred at sites separated by different depths and/or sediment microhabitats. The SIMPROF procedure indicated statistically significant non-random structure among samples ($\pi = 3.34$, $p < 0.01$) and, to some extent an MDS ordination supported the validity of the cluster groups (Figure 5.4B). The SIMPER analysis in PRIMER was used to identify the characteristic species for each cluster group (assemblage) comprised of more than one sample (i.e., groups A, C, E and G), although these taxa are not always the most abundant. For single sample cluster groups (i.e., groups B, D and F), the most abundant taxa were used instead to characterize the assemblages. The top three characteristic or most abundant species for each cluster group as defined above are indicated in Figure 5.4A, while a complete list of all species and their relative abundances in each group is included in Appendix D.1.

Cluster group A represented an assemblage restricted to one northern reference site (station B12) during both the January and July surveys. Abundance averaged 293 individuals per 0.1 m^2, while species richness averaged 92 taxa per grab. The top three species that characterized this assemblage were all polychaetes, including the terebellid *Polycirrus* sp A, the cirratulid *Aphelochaeta glandaria*, and the paraonid *Aricidea catherinae*. Sediments at this site averaged 32% fines over both surveys.

Cluster group B represented a near-ZID assemblage restricted to station E14 sampled during January 2009. Abundance averaged 439 animals per 0.1 m^2 and species richness averaged 98 taxa per grab. The most abundant species that characterized this assemblage was the capitellid polychaete *Capitella teleta* (formerly *Capitella capitata* complex). In fact, *C. teleta* accounted for about 14% of average macrofaunal abundance at station E14 in January, which represented more than 60% of all individuals of this species captured during the year at all of the PLOO stations combined. The next two most abundant species comprising group B included the terebellid *Polycirrus* sp A, and the amphipod *Photis californica*. Sediments at this site were relatively coarse, comprised mostly of coarse sand, gravel and shell hash, along with about 30% fines.

Cluster group C comprised the assemblage that occurred at northern station B11 during July (i.e., this station was not sampled during January 2009; see Materials and Methods), as well as the southern stations E9 and E3. This assemblage had the second highest mean abundance (371 per 0.1 m^2) and the highest species richness (108 taxa) compared to the other cluster groups. The spionid polychaete, *Prionospio dubia* was the dominant species characterizing this assemblage. The next two characteristic species were also polychaetes, and included the cirratulid *Aphelochaeta* sp LA1 and the capitellid *Mediomastus* sp. Sediments at this site were mixed, comprised of about 42% fines along with coarser materials such as black sands, shell hash, gravel, and small rocks.

Cluster group D represented the assemblage at station B8, another northern site located along the 88-m depth contour and that was only sampled during the July survey. This assemblage averaged 294 organisms and 76 taxa per 0.1 m^2, the latter representing the lowest species richness among all groups. The three most abundant species in this assemblage were the ophiuroid *Amphiodia urtica,* followed by the bivalves *Adontorhina cyclia* and *Axinopsida serricata*. The sediments at this site were comprised of 57% fines, the finest sediments among all cluster groups.

Cluster group E represented an assemblage that occurred at two of the southernmost sites located about 2–3 km east of the LA-5 dredged materials disposal site along the 88 and 98-m depth contours. This assemblage averaged 287 individuals per 0.1 m^2 and 89 taxa per grab. The three most characteristic species of this group included the brittle star *Amphiodia urtica*, the bivalve *Ennucula tenuis*, and the spionid *Prionospio dubia*. Sediments at these sites were mixed, averaging 41% fines.

Cluster group F represented an assemblage from northern station B10 located along the 116-m depth contour, which was only sampled during July. This assemblage averaged 354 individuals and 98 taxa per 0.1 m^2. The three most abundant species included *Polycirrus* sp A, *Axinopsida serricata*, and the ostracod *Euphilomedes producta*. The sediments associated with this group were composed of 28% fines with some shell hash.

Cluster group G represented the most wide-spread macrobenthic assemblage present in 2009, comprising animals from 68% of the samples and 14 stations.

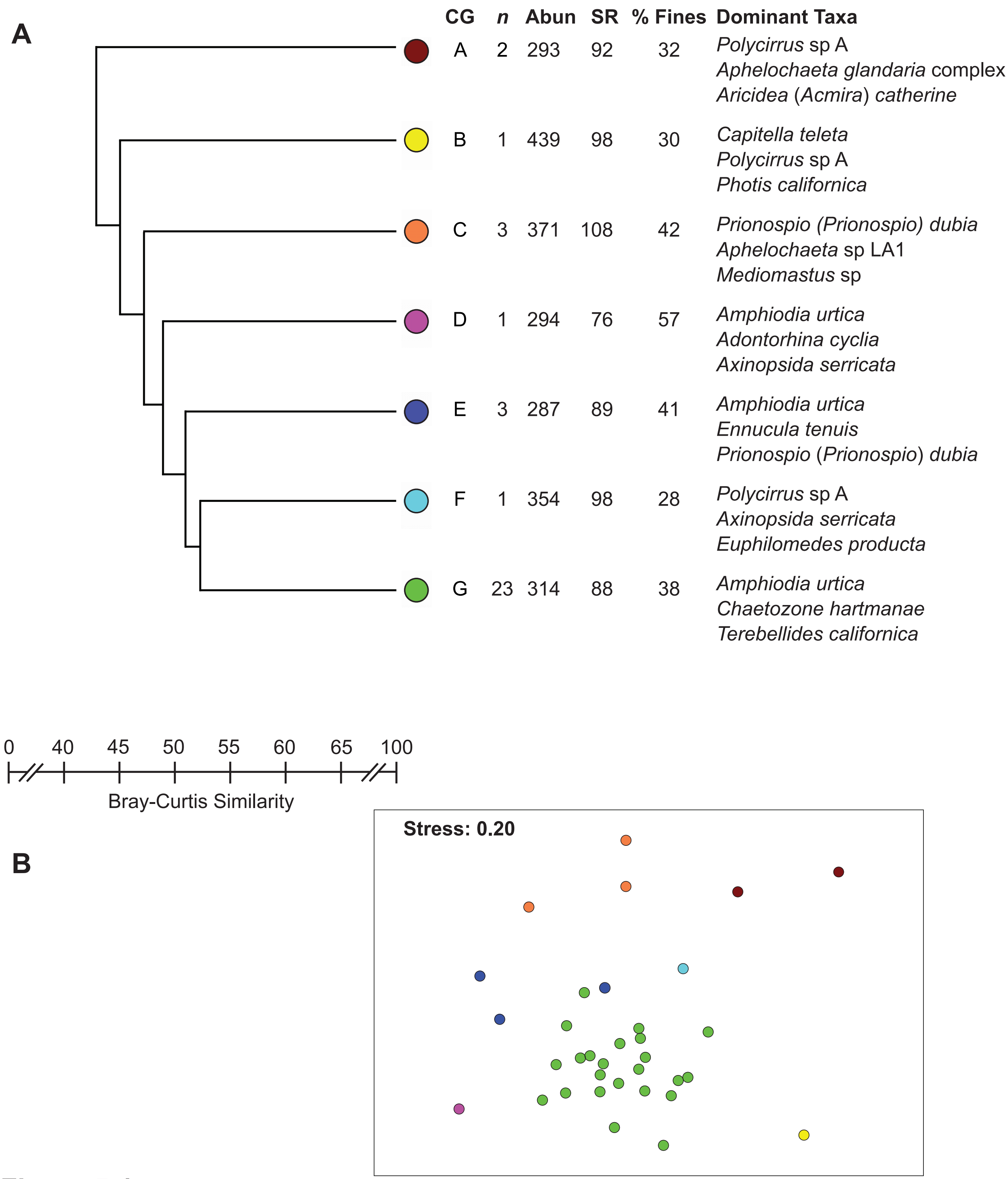


Figure 5.4

(A) Cluster results of the macrofaunal abundance data for the PLOO benthic stations sampled during winter and summer 2009. Data for percent fines, total organic carbon (TOC), species richness (SR), and infaunal abundance (Abun), are expressed as mean values per 0.1-m^2 grab over all stations in each group (CG). (B) MDS ordination based on square-root transformed macrofaunal abundance data for each station/survey entity. Cluster groups superimposed on station/surveys illustrate a distinction between faunal assemblages.

The average abundance for this group was 314 individuals per 0.1 m^2, while species richness averaged 88 taxa per sample. The top three species characterizing group G included *Amphiodia urtica* and two polychaetes, the latter including the cirratulid *Chaetozone hartmanae* and the terebellid *Terebellides californica*. The sediments associated with this assemblage were characterized by some shell hash with 38% fines.

Summary and Conclusions

Benthic communities surrounding the PLOO continue to be dominated by ophiuroid-polychaete based assemblages, with few major changes having occurred since monitoring began (see City of San Diego 1995, 1999, 2009). Polychaetes and ophiuroids are the most abundant and diverse infauna taxa in the region. Although many of the 2009 assemblages were dominated by similar taxa, the relative abundance of these taxa varied among sites. The brittle star *Amphiodia urtica* was the most abundant and widespread taxon, while the bivalve *Axinopsida serricata* was the second most widespread benthic invertebrate. Assemblages similar to those off Point Loma have been described for other areas in the Southern California Bight (SCB) by Barnard and Ziesenhenne (1961), Jones (1969), Fauchald and Jones (1979), Thompson et al. (1987, 1993a), Zmarzly et al. (1994), Diener and Fuller (1995), and Bergen et al. (1998, 2000, 2001).

Although variable, benthic communities off Point Loma generally have remained similar from year to year in terms of the number of species, number of individuals, and dominance (e.g., City of San Diego 1995, 1999, 2007). In addition, values for these parameters in 2009 were similar to those described for other sites throughout the SCB (e.g., Thompson et al. 1993b, Bergen et al. 1998, 2000, 2001; Ranasinghe et al. 2003, 2007). In spite of this overall stability, there has been some increase in the number of species and macrofaunal abundance at some PLOO stations during the post-discharge period (see City of San Diego 1995, 1999, 2007).

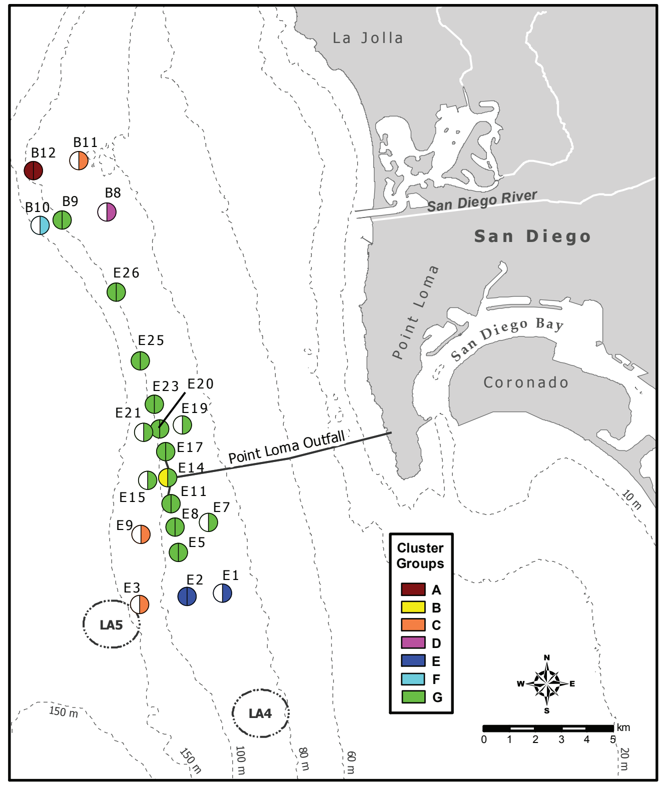


Figure 5.5
Spatial distribution of PLOO macrobenthic assemblages delineated by ordination and classification analyses (see Figure 5.4). Left half of circle represents cluster group affiliation for the January survey; right half represents the July survey.

A few changes near the outfall suggest some effects that may be indicative of anthropogenic activities such as organic enrichment or other types of disturbance. For example, BRI values have increased at near-ZID station E14 since discharge began and are generally higher at this and the two other stations nearest the outfall (E11 and E17) than elsewhere off Point Loma. However, BRI values at these and all other of the PLOO sites still remain characteristic of undisturbed areas (see Smith et al. 2001, Ranasinghe et al. 2010). The increased variability in number of species and infaunal abundance at station E14 since discharge began may be indicative of community destabilization (see Warwick and Clarke 1993, Zmarzly et al. 1994). There have also been changes in sediment composition at E14 since construction of the PLOO (see Chapter 4 herein, City of San Diego 2007). Consequently, changes in community structure near the outfall may be related to localized physical disturbance associated with the outfall pipe structure as well as to organic enrichment.

Populations of some indicator taxa have revealed changes over time that may correspond to organic enrichment near the outfall. For example, there has been a significant change in the difference between brittle star (*Amphiodia* spp) populations that occur nearest the outfall (i.e., station E14) and those present at reference sites since 1997. This difference appears due to both a decrease in ophiuroid numbers near station E14 and a concomitant increase at reference areas during the post-discharge period. Although long term changes in *Amphiodia* populations at E14 may be related to organic enrichment, factors such as altered sediment composition and increased predation pressure near the outfall may also be important. Regardless of the cause of these changes, abundances of *Amphiodia* off Point Loma remain within the range of natural variation in the SCB. Recent increases in populations of the opportunist polychaete *Capitella teleta* may also be indicative of changing benthic conditions. A total of 206 *C. teleta* were reported in 2009 of which 97% occurred at the three stations located within 300 m of the discharge site. Although these abundances represented a noticeable change, they are still relatively low compared to the high densities (e.g., $>5000/m^2$) indicative of polluted sediments (see Swartz et al. 1986). In addition, natural population fluctuations of other resident polychaetes including the oweniid *Myriochele striolata* and terebellid *Proclea* sp A are common off San Diego (Zmarzly et al. 1994, Diener et al. 1995). Further complicating the picture, relatively stable populations of pollution sensitive amphipods in the genus *Rhepoxynius* are not indicative of an outfall-related effect.

While it is difficult to detect specific effects of the PLOO on the offshore benthos region-wide, it is possible to see some changes occurring nearest the discharge site. Because of the minimal extent of these changes, it has not been possible to determine whether observed effects are due to habitat alteration related to organic enrichment, the physical structure of the outfall pipe, or a combination of factors. In addition, abundances of soft bottom invertebrates exhibit substantial spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, 1992b; Otway 1995). The effects associated with the discharge of advanced primary treated sewage may be difficult to detect in areas subjected to strong currents that facilitate the dispersion of the wastewater plume (see Diener and Fuller 1995). Although some changes in macrobenthic assemblages have appeared near the outfall, most assemblages in the Point Loma region are still similar to those observed prior to discharge and to natural indigenous communities characteristic of the southern California continental shelf. Overall, benthic macrofauna appear to be in good condition off Point Loma, with all of the sites surveyed in 2009 being classified in reference condition based on assessments using the benthic response index. This is not unexpected as Ranasinghe et al. (2010) recently reported that 98% of the entire SCB was in good condition based on data gathered during the 1994−2003 bight-wide surveys.

Literature Cited

Barnard, J.L. and F.C. Ziesenhenne. (1961). Ophiuroidea communities of southern Californian coastal bottoms. Pacific Naturalist, 2: 131–152.

Bascom, W., A.J. Mearns, and J.Q. Word. (1979). Establishing boundaries between normal, changed, and degraded areas. In: Southern California Coastal Water Research Project Annual Report, 1978. Long Beach, CA. p 81–95.

Bergen, M., D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull, R.G. Velarde, and S.B. Weisberg. (2000). Assessment of benthic infaunal condition on the mainland shelf of southern California. Environmental Monitoring Assessment, 64: 421–434.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and

R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

Bernstein, B.B. and J. Zalinski. (1983). An optimum sampling design and power tests for environmental biologists. Journal of Environmental Management, 16: 35–43.

Bilyard, G.R. (1987). The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin, 18(11): 581–585.

City of San Diego. (1995). Outfall Extension Pre-Construction Monitoring Report. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Diener, D.R. and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. Bulletin of the Southern California Academy of Science, 94: 5–20.

Diener, D.R., S.C. Fuller, A. Lissner, C.I. Haydock, D. Maurer, G. Robertson, and R. Gerlinger. (1995). Spatial and temporal patterns of the infaunal community near a major ocean outfall in southern California. Marine Pollution Bulletin, 30: 861–878.

Fauchald, K. and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. Report 19, Series 2. In: Southern California Outer Continental Shelf Environmental Baseline Study, 1976/1977 (Second Year) Benthic Program. Principal Investigators Reports, Vol. II. Science Applications, Inc. La Jolla, CA.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and W.A. Deben. (1994). Optimum macrobenthic sampling protocol for detecting pollution impacts in the Southern California Bight. Environmental Monitoring and Assessment, 29: 127–153.

Gray, J.S. (1979). Pollution-induced changes in populations. Philosophical Transactions of the Royal Society of London (Series B.), 286: 545–561.

Hartley, J.P. (1982). Methods for monitoring offshore macrobenthos. Marine Pollution Bulletin, 12: 150–154.

Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monographs of Marine Biology, 4: 1–219.

Morrisey, D.J., L. Howitt, A.J. Underwood, and J.S. Stark. (1992a). Spatial variation in soft-sediment benthos. Marine Ecology Progress Series, 81: 197–204.

Morrisey, D.J., A.J. Underwood, L. Howitt, and J.S. Stark. (1992b). Temporal variation in soft-sediment benthos. Journal of Experimental Marine Biology and Ecology, 164: 233–245.

Osenberg, C.W., R.J. Schmitt, S.J. Holbrook, K.E. Abu-Saba, and A.R. Flegel. (1994). Detection of environmental impacts: Natural variability, effect size, and power analysis. Ecological Applications, 4: 16–30.

Otway, N.M. (1995). Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. Marine Pollution Bulletin, 31: 347–354.

Pearson, T.H. and R. Rosenberg. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16: 229–311.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., K.C. Schiff, D.E. Montagne, T.K. Mikel, D.B. Cadien, R.G. Velarde, and C.A. Brantley. (2010). Benthic macrofaunal community condition in the Southern California Bight, 1994–2003. Marine Pollution Bulletin, 60: 827–833.

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications, 11(4): 1073–1087.

Smith, R.W. and L. Riege. (1994). Optimization and power analyses for the Point Loma monitoring design. Unpublished report to City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Snelgrove P.V.R., T.H. Blackburn, P.A. Hutchings, D.M. Alongi, J.F. Grassle, H. Hummel, G. King, I. Koike, P.J.D. Lambshead, N.B. Ramsing, V. Solis-Weiss. (1997). The importance of marine sediment biodiversity in ecosystem processes. Ambio, 26: 578–583.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. (1986). Environmental impact assessment: "Pseudoreplication" in time? Ecology, 67: 929–940.

Stewart-Oaten, A., J.R. Bence, and C.W. Osenberg. (1992). Assessing effects of unreplicated perturbations: no simple solutions. Ecology, 73: 1396–1404.

Swartz, R.C., F.A. Cole, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B.E., J. Dixon, S. Schroeter, and D.J. Reish. (1993a). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 369–458.

Thompson, B.E., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 reference site survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B.E., D. Tsukada, and D. O'Donohue. (1993b). 1990 reference site survey. Technical Report No. 269, Southern California Coastal Water Research Project, Long Beach CA.

[U.S. EPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

Warwick, R.M. and K.R. Clarke. (1993). Increased variability as a symptom of stress in marine communities. Journal of Experimental Marine Biology and Ecology, 172: 215–226.

Word, J.Q. (1980). Classification of benthic invertebrates into infaunal trophic index feeding groups. In: W. Bascom (ed.). Biennial Report for the Years 1979–1980, Southern California Coastal Water Research Project, Long Beach, CA.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: Relation to anthropogenic and natural events. Marine Biology, 118: 293–307.

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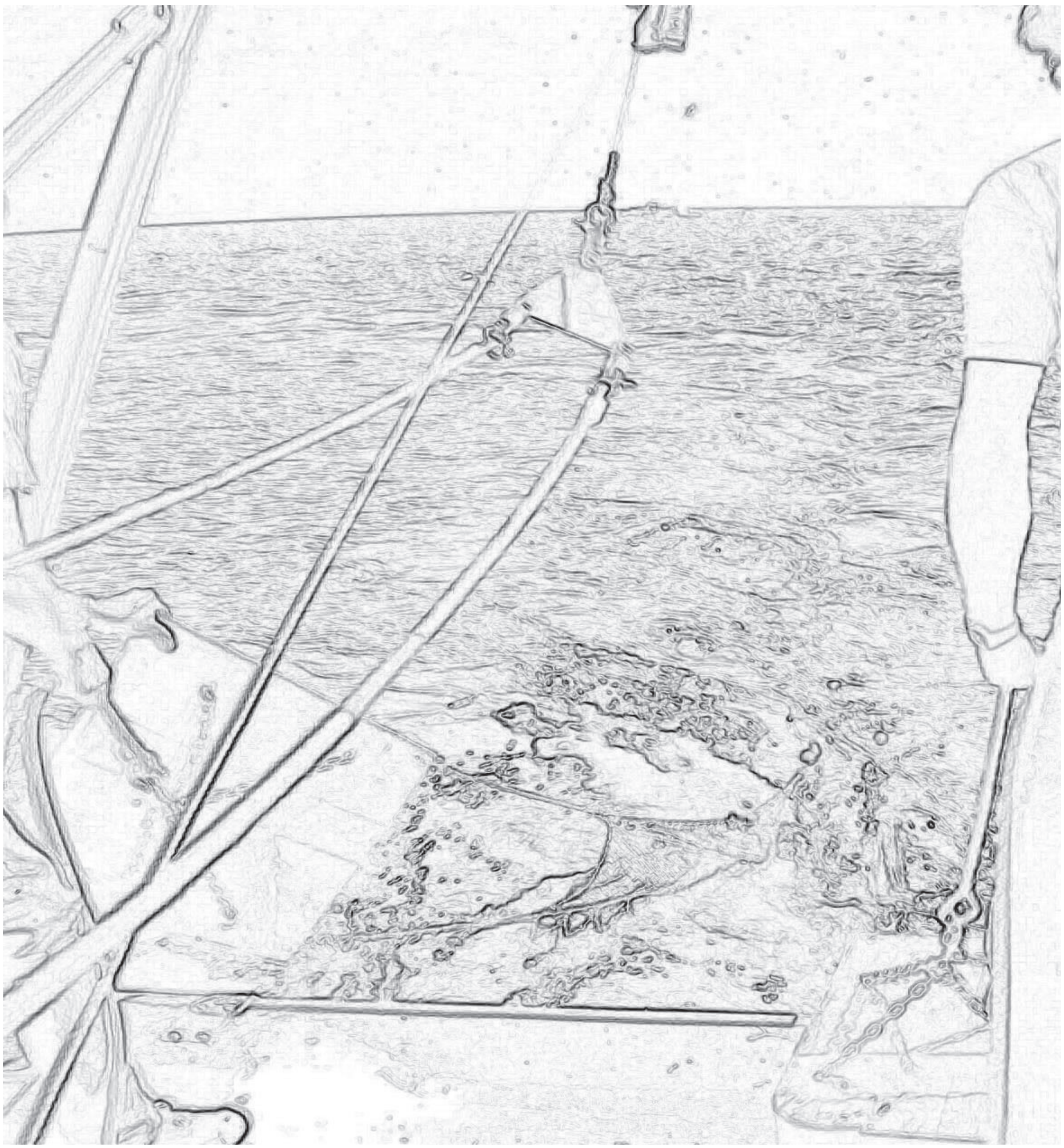
Chapter 6
Demersal Fishes
and Megabenthic Invertebrates



Chapter 6. Demersal Fishes and Megabenthic Invertebrates

INTRODUCTION

Marine fishes and invertebrates are conspicuous members of continental shelf habitats, and assessment of their communities has become an important focus of ocean monitoring programs throughout the world. Assemblages of bottom dwelling (demersal) fishes and relatively large (megabenthic), mobile invertebrates that live on the surface of the seafloor have been sampled extensively for more than 30 years on the mainland shelf of the Southern California Bight (SCB), primarily by programs associated with municipal wastewater and power plant discharges (Cross and Allen 1993). More than 100 species of demersal fishes inhabit the SCB, while the megabenthic invertebrate fauna consists of more than 200 species (Allen 1982, Allen et al. 1998, 2002, 2007). For the region surrounding the Point Loma Ocean Outfall (PLOO), the most common trawl-caught fishes include Pacific sanddab, longfin sanddab, Dover sole, hornyhead turbot, California tonguefish, plainfin midshipman, and yellowchin sculpin. Common trawl-caught invertebrates include various echinoderms (e.g., sea stars, sea urchins, sea cucumbers, and sand dollars), crustaceans (e.g., crabs and shrimp), molluscs (e.g., marine snails and octopuses), and other taxa.

Demersal fish and megabenthic invertebrate communities are inherently variable and may be influenced by both anthropogenic and natural factors. These organisms live in close proximity to the seafloor and are therefore exposed to contaminants of anthropogenic origin that may accumulate in the sediments via deposition from both point and non-point sources (e.g., discharges from ocean outfalls and storm drains, surface runoff from watersheds, outflows from rivers and bays, disposal of dredge materials). Natural factors that may affect these organisms include prey availability (Cross et al. 1985), bottom relief and sediment structure (Helvey and Smith 1985), and changes in water temperatures associated with large scale oceanographic events such as El Niño/La Niña oscillations (Karinen et al. 1985). These factors can affect migration patterns of adult fish or the recruitment of juveniles into an area (Murawski 1993). Population fluctuations that affect species diversity and abundance of both fishes and invertebrates may also be due to the mobile nature of many species (e.g., fish schools, urchin aggregations).

The City of San Diego has been conducting trawl surveys in the area surrounding the present discharge site for the PLOO since 1991. These surveys are designed to monitor the effects of wastewater discharge on the local marine biota by assessing the structure and stability of the trawl-caught fish and invertebrate communities. This chapter presents analyses and interpretations of the data collected during the 2009 trawl surveys. A long-term analysis of changes in these communities from 1991 through 2009 is also presented.

Materials and Methods

Field Sampling

Trawl surveys were conducted at six fixed monitoring sites in the Point Loma region during 2009 (Figure 6.1). The six trawl stations, designated SD7, SD8, SD10, SD12, SD13 and SD14, are located along the 100-m depth contour, and encompass an area ranging from about 8 km north to 9 km south of the PLOO. A total of eight trawls were taken during two surveys in 2009. Sampling in January (winter) was limited to the two stations located nearest the outfall due to a resource exchange agreement to allow participation in the Bight'08 regional monitoring program (see Chapter 1), whereas all six stations were sampled during the July (summer) survey. A single trawl was performed at each station during each survey using a 7.6-m Marinovich otter

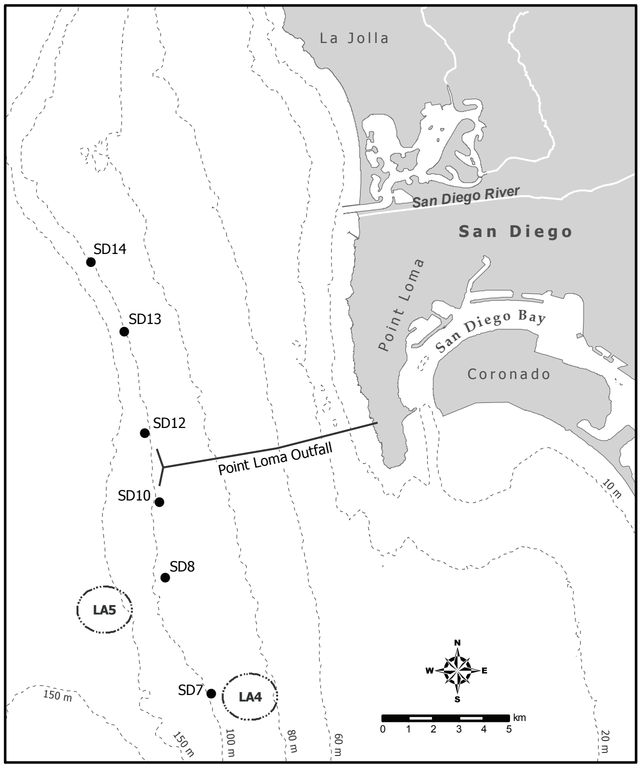


Figure 6.1
Otter trawl station locations, Point Loma Ocean Outfall Monitoring Program.

trawl fitted with a 1.3-cm cod-end mesh net. The net was towed for 10 minutes bottom time at a speed of about 2.0 knots along a predetermined heading.

The total catch from each trawl was brought onboard ship for sorting and inspection. All fishes and invertebrates captured were identified to species or to the lowest taxon possible. If an animal could not be identified in the field, it was returned to the laboratory for further identification. For fishes, the total number of individuals and total biomass (kg, wet weight) were recorded for each species. Additionally, each individual fish was inspected for physical anomalies or indicators of disease (e.g., tumors, fin erosion, discoloration) as well as the presence of external parasites, and then measured to the nearest centimeter size class (standard lengths). For invertebrates, the total number of individuals was recorded per species. Due to the small size of most organisms, invertebrate biomass was typically measured as a composite weight of all species combined; however, large or exceptionally abundant species were weighed separately.

Data Analyses

Populations of each fish and invertebrate species were summarized as percent abundance, frequency of occurrence, mean abundance per haul, and mean abundance per occurrence. In addition, species richness (number of taxa), total abundance, total biomass, and Shannon diversity index (H') were calculated for each station. For historical comparisons, the data were grouped as “nearfield” stations (SD10, SD12), “south farfield” stations (SD7, SD8), and “north farfield” stations (SD13, SD14). The two nearfield stations were those located closest to the outfall (i.e., within 1000 m of the north or south diffuser legs).

A long-term multivariate analysis of demersal fish communities in the region was performed using data collected from 1991 through 2009. However, in order to eliminate noise due to natural seasonal variation in populations, this analysis was limited to data for the July surveys only over these 19 years. PRIMER software was used to examine spatio-temporal patterns in the overall similarity of fish assemblages in the region (see Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking, and ordination by non-metric multidimensional scaling (MDS). The fish abundance data were square-root transformed and the Bray-Curtis measure of similarity was used as the basis for classification. Because species composition was sparse at some stations, a “dummy” species with a value of one was added to all samples prior to computing similarities (see Clarke and Gorley 2006). SIMPER analysis was subsequently used to identify which species primarily account for observed differences between cluster groups, as well as to identify species typical of each group.

Results and Discussion

Fish Community

Twenty-six species of fish were collected in the area surrounding the PLOO in 2009 (Table 6.1,

Table 6.1

Demersal fish species collected in eight trawls in the PLOO region during 2009. PA = percent abundance; FO = frequency of occurrence; MAO = mean abundance per occurrence; MAH = mean abundance per haul.

Species	PA	FO	MAO	MAH	Species	PA	FO	MAO	MAH
Pacific sanddab	50	100	102	102	California tonguefish	1	50	3	1
California lizardfish	11	75	30	22	Yellowchin sculpin	1	25	6	1
Halfbanded rockfish	8	100	16	16	California scorpionfish	<1	13	8	1
Dover sole	6	100	13	13	Spotted cuskeel	<1	50	2	1
Longspine combfish	6	100	13	13	Roughback sculpin	<1	38	2	1
Shortspine combfish	5	100	10	10	Bigmouth sole	<1	25	3	1
English sole	3	88	7	6	Longfin sanddab	<1	25	1	<1
Pink seaperch	2	75	6	5	White croaker	<1	13	2	<1
Plainfin midshipman	2	100	4	4	Bluebanded ronquil	<1	13	1	<1
Slender sole	2	63	5	3	Flag rockfish	<1	13	1	<1
Stripetail rockfish	1	63	3	2	Smooth stargazer	<1	13	1	<1
Hornyhead turbot	1	63	3	2	Spotfin sculpin	<1	13	1	<1
Greenstriped rockfish	1	63	2	2	Wolf-eel	<1	13	1	<1

Appendix E.1). The total catch for the year was 1645 individuals, representing an average of about 206 fish per trawl. As in previous years, Pacific sanddabs were dominant, occurring in every haul and accounting for 50% of the total number of fishes collected. Halfbanded rockfish, Dover sole, longspine combfish, shortspine combfish, and plainfin midshipman were also collected in every haul, but in much lower numbers. Other species collected frequently (≥75% of the trawls) included California lizardfish, English sole, and pink seaperch. Pacific sanddabs averaged 102 fish per occurrence, while all other species averaged 30 or less with each contributing to no more than 11% of the total catch. The majority of species captured in the Point Loma region tended to be relatively small fish with an average length ≤20 cm (see Appendix E.1). Although larger species such as the California scorpionfish and wolf-eel were also captured during the year, these fish were relatively rare.

No more than 17 species of fish occurred in any one haul during 2009, and the corresponding diversity (H') values were all less than 2.2 (Table 6.2). Total abundance ranged from 108 to 377 fishes per haul; these differences tended to reflect variation in Pacific sanddab populations, which ranged between 27–167 fish per catch (Appendix E.2). Fish biomass ranged from 3.5 to 9.7 kg per haul, with higher values coincident with either greater numbers of fishes or the presence of large individual fish. For example, the highest biomass measured during the year was 9.7 kg at station SD10 in January, which was due to both a large haul of Pacific sanddabs weighing 4.3 kg and a large wolf-eel with an individual weight of 2.5 kg (see Appendix E.3).

Large fluctuations in populations of a few dominant species have been the primary factor contributing to the high variation in fish community structure off Point Loma since 1991 (Figure 6.2, 6.3). For example, species richness values for individual trawls performed within the PLOO region over this time period have ranged from 7 to 26 species, while total abundance per haul has varied from 44 to 2322 individuals/station/survey. The fluctuations in abundance have been greatest at stations SD10, SD12, SD13 and SD14 and generally reflect differences in populations of several dominant species. For example, overall abundance has been low since January 2007 due to significantly fewer numbers of Pacific sanddabs, yellowchin sculpin, longspine combfish, Dover sole, and halfbanded rockfish captured during each survey at most stations. Moreover, changes in dominant species over time have generally been similar among stations near the outfall and those at the northern sites. None of the observed changes in fish populations appear to be associated with wastewater discharge.

Table 6.2

Summary of demersal fish community parameters for PLOO stations sampled during 2009. Data are included for species richness (number of species), abundance (number of individuals), diversity (H'), and biomass (kg, wet weight); ns = not sampled; SD = standard deviation.

Station	Winter	Summer
Species Richness		
SD7	ns	12
SD8	ns	17
SD10	15	13
SD12	12	14
SD13	ns	14
SD14	ns	14
Survey Mean	14	14
Survey SD	2	2
Abundance		
SD7	ns	163
SD8	ns	185
SD10	222	108
SD12	143	377
SD13	ns	151
SD14	ns	296
Survey Mean	183	213
Survey SD	56	102
Diversity		
SD7	ns	1.11
SD8	ns	1.64
SD10	1.53	1.40
SD12	2.19	1.81
SD13	ns	1.89
SD14	ns	1.68
Survey Mean	1.86	1.59
Survey SD	0.46	0.29
Biomass		
SD7	ns	4.3
SD8	ns	5.5
SD10	9.7	3.5
SD12	8.6	6.2
SD13	ns	4.4
SD14	ns	9.2
Survey Mean	9.1	5.5
Survey SD	0.8	2.0

Ordination and classification analyses of fish abundance data from 1991 through 2009 distinguished between eight main cluster groups or assemblages (cluster groups A–H; see Figure 6.4). These results indicate that the demersal fish community off Point Loma remains dominated by Pacific sanddabs, with differences in the relative abundance of this or other common species discriminating between the different cluster groups (see Table 6.3, Appendix E.4). During 2009, assemblages at all of the stations except SD10 were similar to those that occurred during 2006–2008 at all stations except SD7 (see description of group G below). There do not appear to be any spatial or temporal patterns that can be attributed to the outfall or the onset of wastewater discharge. Instead, most differences in local fish assemblages appear to be more closely related to large-scale oceanographic events (e.g., El Niño conditions in 1998) or the unique characteristics of a specific station. For example, fish assemblages at stations SD7 and SD8 located south of the outfall and not far from the LA-4 and LA-5 disposal sites, respectively, often grouped apart from the remaining trawls stations. The composition and main characteristics of each cluster group are described in the paragraphs that follow.

Cluster groups A–E comprised five unique assemblages, each represented by 1–3 station/survey entities (i.e., trawl catches), and accounting for <8% of the total number of trawls. Although most of these groups were dominated by Pacific sanddabs, they were unique compared to the other assemblages (i.e., cluster groups F–H) in terms of lower total abundance, fewer species, and/or relatively high numbers of less common fishes (e.g, midshipman, rockfish). Cluster group A represented the assemblage from station SD10 sampled in 1997, which was characterized by the fewest species and total number of fish per haul (i.e., 7 species, 44 fish), as well as the fewest Pacific sanddabs. Cluster group B represented the catch from stations SD7 and SD8 sampled in 2001, while group C was comprised of trawls from station SD8 in 1994, SD14 in 1998, and SD10 in 2009. These two assemblages were characterized by a few more species than group A (i.e., 11 species), and both groups also had low total abundances and relatively low average numbers of Pacific sanddabs. Cluster group D represented the assemblage from station SD12 sampled in 1998. This assemblage was unique because of the occurrence of a large population of plainfin midshipman, as well as a few less common

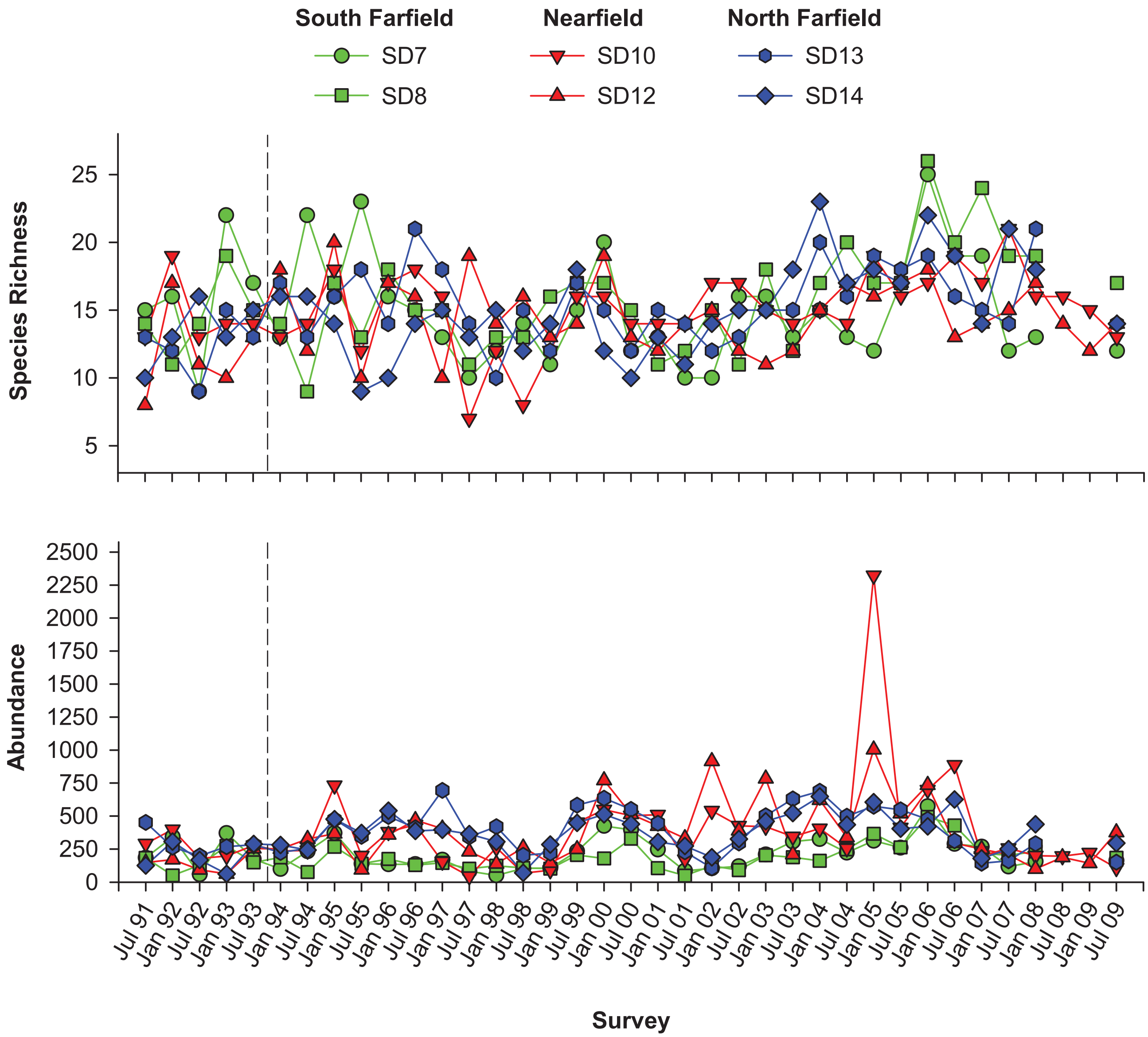


Figure 6.2
Species richness and abundance of demersal fish collected at each PLOO trawl station between 1991 and 2009. Data are total number of species and total number of individuals per haul, respectively. Dashed line represents initiation of wastewater discharge.

species (e.g., gulf sanddab). Cluster group E represented the assemblage from station SD12 sampled in 1997, which had the highest number of species over all groups, and was distinguished from other assemblages by relatively high numbers of halfbanded rockfish and squarespot rockfish.

Cluster group F represented the assemblage characteristic of 30 trawls. This included 18 of 24 trawls at stations SD7 and SD8 sampled between 1991–2002, trawls from all of the other stations (i.e., SD10–SD14) sampled during 1991–1992, and trawls from stations SD10 and SD12 in 1995, station SD10 in 1998, and station SD7 in 2007. Overall, this group was characterized by moderate numbers of fishes and slightly different species composition. The Pacific sanddab was the dominant species in this group with an average of about 97 fish/haul, while the Dover sole and longfin sanddab were the next two most characteristic species. The

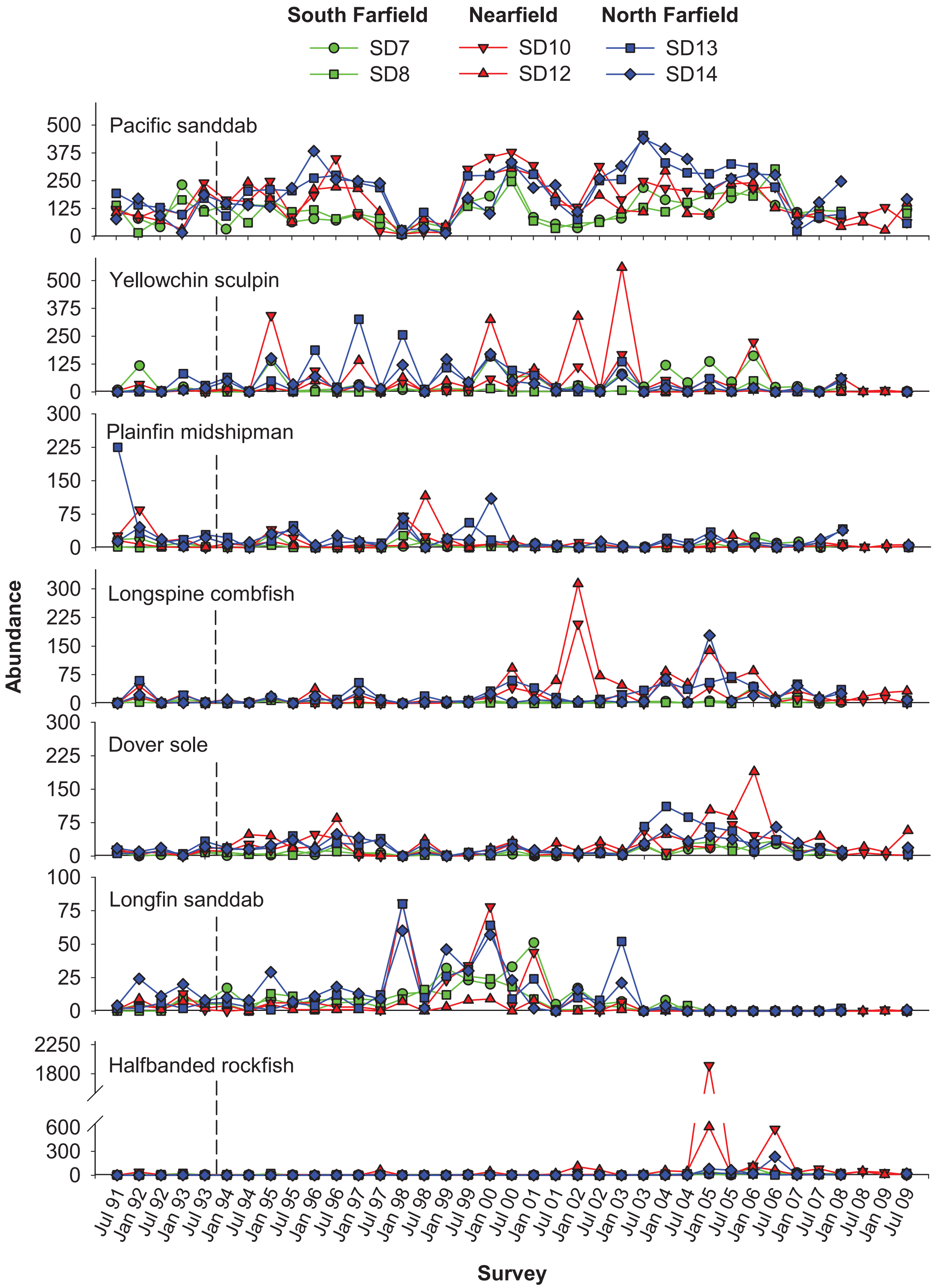


Figure 6.3
The seven most abundant fish species collected in the PLOO region from 1991 through 2009. Data are total number of individuals per haul. Dashed line represents initiation of wastewater discharge.

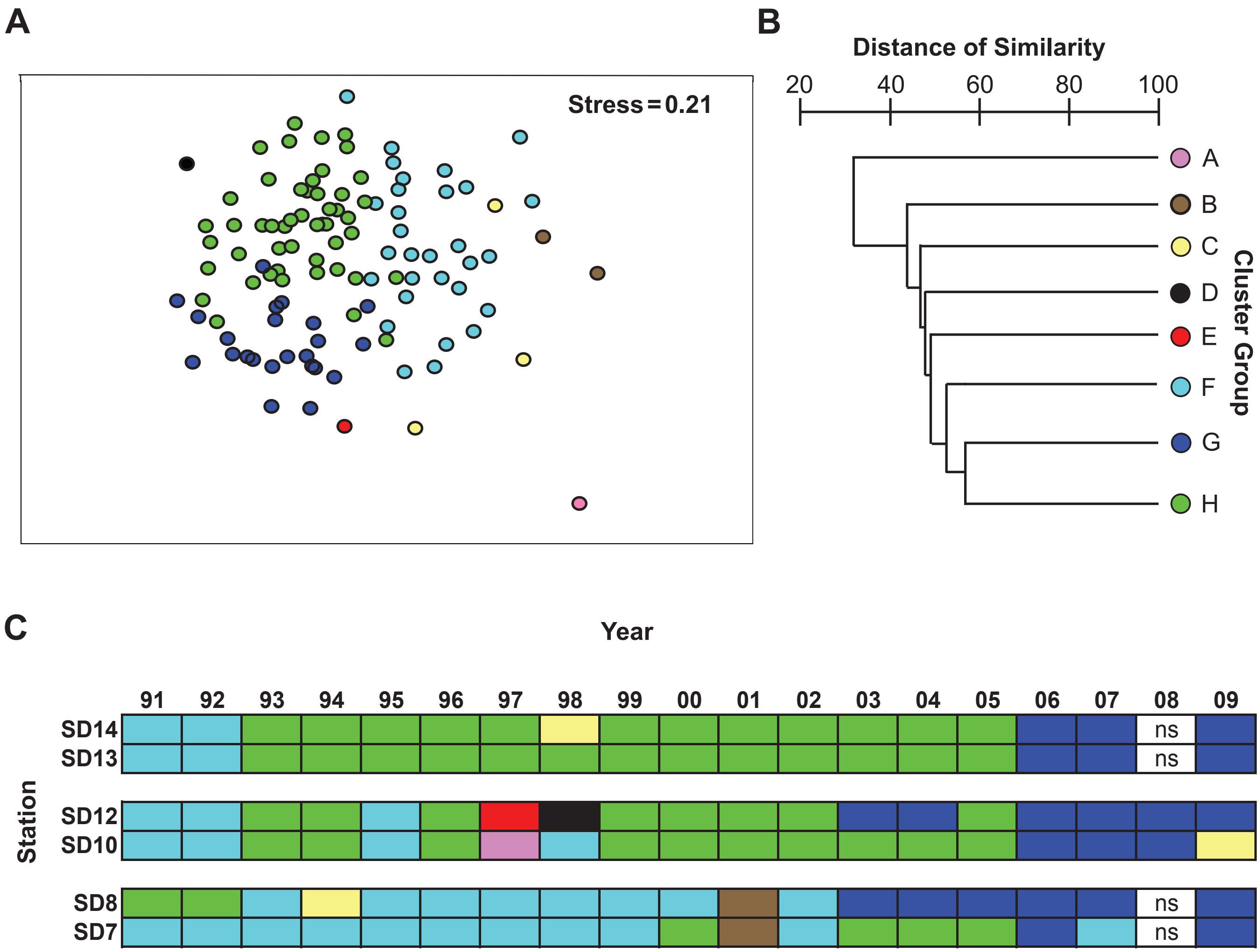


Figure 6.4

Results of classification analysis of demersal fish assemblages collected at PLOO stations SD7–SD14 between 1991 and 2009 (July surveys only). Data are presented as (A) MDS ordination, (B) a dendrogram of major cluster groups, and (C) a matrix showing distribution of cluster groups over time; ns = not sampled.

relative abundances of the above three species plus halfbanded rockfish, stripetail rockfish, plainfin midshipman, and squarespot rockfish distinguished this cluster group from all others.

Cluster group G comprised the assemblages from all but one station sampled during 2009, as well as the only two stations sampled during the July 2008 survey (i.e., SD10, SD12), all stations except SD7 in 2006 and 2007, SD12 during 2003–2004, and SD8 between 2003 and 2005. This group was characterized by relatively high numbers of Pacific sanddabs (~142 fish/haul), halfbanded rockfish (~55 fish/haul), and Dover sole (~26 fish/haul). The higher abundances of these three species helped distinguish this group from all others.

Cluster group H may represent "normal" or "background" conditions in the PLOO region, representing assemblages from 45% of all trawls included in the analysis. Most of these assemblages were sampled at stations around or north of the PLOO between 1993 and 2005 (i.e., stations SD10–SD14). The main exceptions occurred during and after the 1998 El Niño (i.e., 1997–1999). This group was characterized by the highest average numbers of Pacific sanddabs (~239 fish/haul) and the second highest average numbers of Dover sole (~29 fish/haul). The next three most abundant species in this group

Table 6.3

Description of cluster groups A–H defined in Figure 6.4. Data include number of hauls, mean species richness, mean total abundance, and mean abundance of the five most abundant species for each station group. Bold values indicate species that were considered “characteristic” of that group according to SIMPER analyses (i.e., similarity/standard deviation ≥ 2.0).

	Cluster Groups							
	A	B	C	D	E	F	G	H
Number of Hauls	1	2	3	1	1	30	23	49
Mean Species Richness	7	11	11	16	19	13	16	15
Mean Abundance	44	68	85	261	231	162	292	363
Species	**Mean Abundance**							
Pacific sanddab	23.0	45.5	**52.7**	75.0	110.0	**97.4**	**142.4**	**239.0**
Dover sole	—	1.0	**4.3**	36.0	1.0	**10.0**	**25.5**	**29.4**
Yellowchin sculpin	—	5.0	—	—	—	3.5	1.5	16.9
Longspine combfish	—	2.5	1.7	7.0	2.0	0.7	11.1	14.3
Stripetail rockfish	—	—	5.0	1.0	5.0	8.3	2.4	13.2
Plainfin midshipman	—	—	**2.0**	116.0	4.0	14.6	4.1	8.9
Halfbanded rockfish	16.0	—	1.3	—	60.0	1.8	**55.8**	6.7
Longfin sanddab	1.0	3.0	0.7	—	—	**6.8**	0.2	5.9
Pink seaperch	1.0	0.5	1.0	4.0	1.0	0.9	4.3	4.6
Shortspine combfish	—	—	0.3	—	3.0	2.1	11.4	2.1
Greenblotched rockfish	—	0.5	1.0	—	8.0	0.7	0.4	1.2
Bigmouth sole	—	2.5	—	—	1.0	0.9	0.7	0.8
California tonguefish	—	2.5	—	—	1.0	3.3	1.8	0.8
Gulf sanddab	1.0	—	0.7	5.0	—	0.2	—	0.7
Greenspotted rockfish	1.0	—	—	—	1.0	0.4	—	0.4
California lizardfish	—	1.0	8.7	—	—	0.5	7.5	0.4
Roughback sculpin	—	1.5	0.3	2.0	—	0.3	0.6	0.3
Spotfin sculpin	1.0	—	1.0	—	—	2.1	1.8	0.2
Squarespot rockfish	—	0.5	—	—	23.0	0.1	0.1	—
Vermilion rockfish	—	—	—	—	6.0	—	—	—

were yellowchin sculpin (17 fish/haul), longspine combfish (~14 fish/haul), and stripetail rockfish (13 fish/haul). The higher numbers of these five species, plus moderate numbers of longfin sanddab, plainfin midshipman and halfbanded rockfish, distinguished group H from the other assemblages.

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the PLOO region during 2009. There were no incidences of fin rot, discoloration, skin lesions, tumors or any other indicators of disease among fishes collected during the year. Evidence of parasitism was also very low for trawl-caught fishes off Point Loma. Although the copepod *Phrixocephalus cincinnatus* infected ~2% of the Pacific sanddabs collected during the year, this eye parasite was found on fish collected during each survey, and at least once from each station. In addition, three *Elthusa vulgaris* (Isopoda, Cymothoidae) were identified as part of the trawl catch throughout the year (see Appendix E.5). Since cymothoids often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on sanddabs and California lizardfish in southern California waters, where it may reach infestation rates of 3% and 80%, respectively (see Brusca 1978, 1981).

Table 6.4

Species of megabenthic invertebrates collected in eight trawls in the PLOO region during 2009. PA = percent abundance; FO = frequency of occurrence; MAO = mean abundance per occurrence; MAH = mean abundance per haul.

Species	PA	FO	MAO	MAH	Species	PA	FO	MAO	MAH
Lytechinus pictus	92	100	1229	1229	*Amphichondrius granulatus*	<1	13	<1	1
Strongylocentrotus fragilis	3	25	46	184	*Armina californica*	<1	13	<1	1
Acanthoptilum sp	3	100	44	44	*Hololepida magna*	<1	13	<1	1
Ophiura luetkenii	1	88	8	9	*Luidia asthenosoma*	<1	13	<1	1
Luidia foliolata	<1	50	3	6	*Octopus rubescens*	<1	13	<1	1
Parastichopus californicus	<1	88	3	3	*Paguristes turgidus*	<1	13	<1	1
Sicyonia ingentis	<1	38	2	4	*Pteropurpura* sp	<1	13	<1	1
Astropecten verrilli	<1	50	1	2	*Pyromaia tuberculata*	<1	13	<1	1
Philine alba	<1	38	1	2	*Spatangus californicus*	<1	13	<1	1
Rossia pacifica	<1	25	<1	2	*Suberites* sp	<1	13	<1	1
Elthusa vulgaris	<1	13	<1	3	*Telesto californica*	<1	13	<1	1
Megasurcula carpenteriana	<1	25	<1	1	*Thesea* sp B	<1	13	<1	1
Metridium farcimen	<1	13	<1	2					

Invertebrate Community

A total of 10,702 megabenthic invertebrates (~1338 per trawl) representing 25 taxa were collected during 2009 (Table 6.4, Appendix E.5). As in previous years, the sea urchin *Lytechinus pictus* was the most abundant and most frequently captured species, occurring in all trawls and accounting for 92% of the total invertebrate abundance. The sea pen *Acanthoptilum* sp was also collected in every haul, but in much lower numbers. Other common species that occurred in 50% or more of the hauls included the brittle star *Ophiura luetkenii,* the sea cucumber *Parastichopus californicus,* and the sea stars *Astropecten verrilli* and *Luidia foliolata*.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). Species richness ranged from 5 to 11 species per haul, diversity (H') values ranged from 0.04 to 1.09 per haul, and total abundance ranged from 234 to 3844 individuals per haul. Patterns in total invertebrate abundance tended to mirror variation in *L. pictus* populations (Appendix E.6). For example, stations SD8, SD10, and SD12 had much higher invertebrate abundances than the other three stations due to relatively large catches of *L. pictus* (i.e., ≥1300/haul). The low diversity values (≤1.09) for the region were due to the numerical dominance of this sea urchin. Dominance of *L. pictus* is typical for these types of habitats throughout the SCB (e.g., Allen et al. 1998).

Invertebrate species richness and abundances have varied over time (Figure 6.5). For example, species richness has ranged from 3 to 29 species per year since 1991, although patterns of change have been similar among stations. In contrast, changes in total abundance have differed greatly among the trawl stations. The average annual invertebrate catches have been consistently low at stations SD13 and SD14, while the remaining stations have demonstrated large fluctuations in abundance. These fluctuations typically reflect changes in *L. pictus* populations, as well as populations of *Acanthoptilum* sp, the sea urchin *Strongylocentrotus fragilis*, the shrimp *Sicyonia ingentis*, and the sea star *Astropecten verrilli* (Figure 6.6). Additionally, abundances of *L. pictus* and *A. verrilli* are typically much lower at the two northern sites, which likely reflect differences in sediment composition (e.g., fine sands vs. mixed coarse/fine sediments, see Chapter 4). None of the observed variability in the trawl-caught invertebrate community appeared related to the discharge of wastewater from the PLOO.

Table 6.5
Summary of megabenthic invertebrate community parameters for PLOO stations sampled during 2009. Data are included for species richness (number of species), abundance (number of individuals), and diversity (H'); ns = not sampled; SD = standard deviation.

Station	Winter	Summer
Species Richness		
SD7	ns	7
SD8	ns	11
SD10	6	9
SD12	5	9
SD13	ns	8
SD14	ns	9
Survey Mean	6	9
Survey SD	1	1
Abundance		
SD7	ns	754
SD8	ns	1386
SD10	2110	1536
SD12	3844	251
SD13	ns	234
SD14	ns	587
Survey Mean	2977	791
Survey SD	1226	557
Diversity		
SD7	ns	0.15
SD8	ns	0.10
SD10	0.04	0.09
SD12	0.13	0.73
SD13	ns	1.09
SD14	ns	1.08
Survey Mean	0.08	0.54
Survey SD	0.06	0.48

Summary and Conclusions

Pacific sanddabs continued to dominate fish assemblages surrounding the Point Loma Ocean Outfall during 2009 as they have for many years. This species occurred at all stations and accounted for 50% of the total fish catch. Other characteristic, but less abundant species of fish included halfbanded rockfish, Dover sole, longspine combfish, shortspine combfish, plainfin midshipman, California lizardfish, English sole, and pink seaperch. Most of these common fishes were relatively small, averaging less than 20 cm in length. Although the composition and structure of the fish assemblages varied among stations, most differences were due to fluctuations in Pacific sanddab populations.

Assemblages of megabenthic invertebrates in the region were similarly dominated by a single species, the sea urchin *Lytechinus pictus.* Variations in overall community structure of the trawl-caught invertebrates generally reflect changes in the abundance of this urchin, as well as several other dominant species. These other species include the sea pen *Acanthoptilum* sp, the sea stars *Astropecten verrilli* and *Luidia foliolata*, the sea cucumber *Parastichopus californicus*, and the brittle star *Ophiura luetkenii*.

Overall, results of the 2009 trawl surveys provide no evidence that wastewater discharged through the PLOO has affected either demersal fish or megabenthic invertebrate communities in the region. Although highly variable, patterns in the abundance and distribution of trawl-caught fishes and invertebrates were similar at stations located near the outfall and farther away. These results are supported by the findings of another recent assessment of these communities off San Diego (City of San Diego 2007). Significant changes in these communities appear most likely to be due to natural factors such as changes in ocean water temperatures associated with large-scale oceanographic events or to the mobile nature of many of resident species. Finally, the absence of disease or other physical abnormalities in local fishes suggests that their populations continue to be healthy off Point Loma.

Literature Cited

Allen, M.J. (1982). Functional structure of soft-bottom fish communities of the southern California shelf. Ph.D. dissertation. University of California, San Diego. La Jolla, CA.

Allen, M.J. (2005). The check list of trawl-caught fishes for Southern California from depths

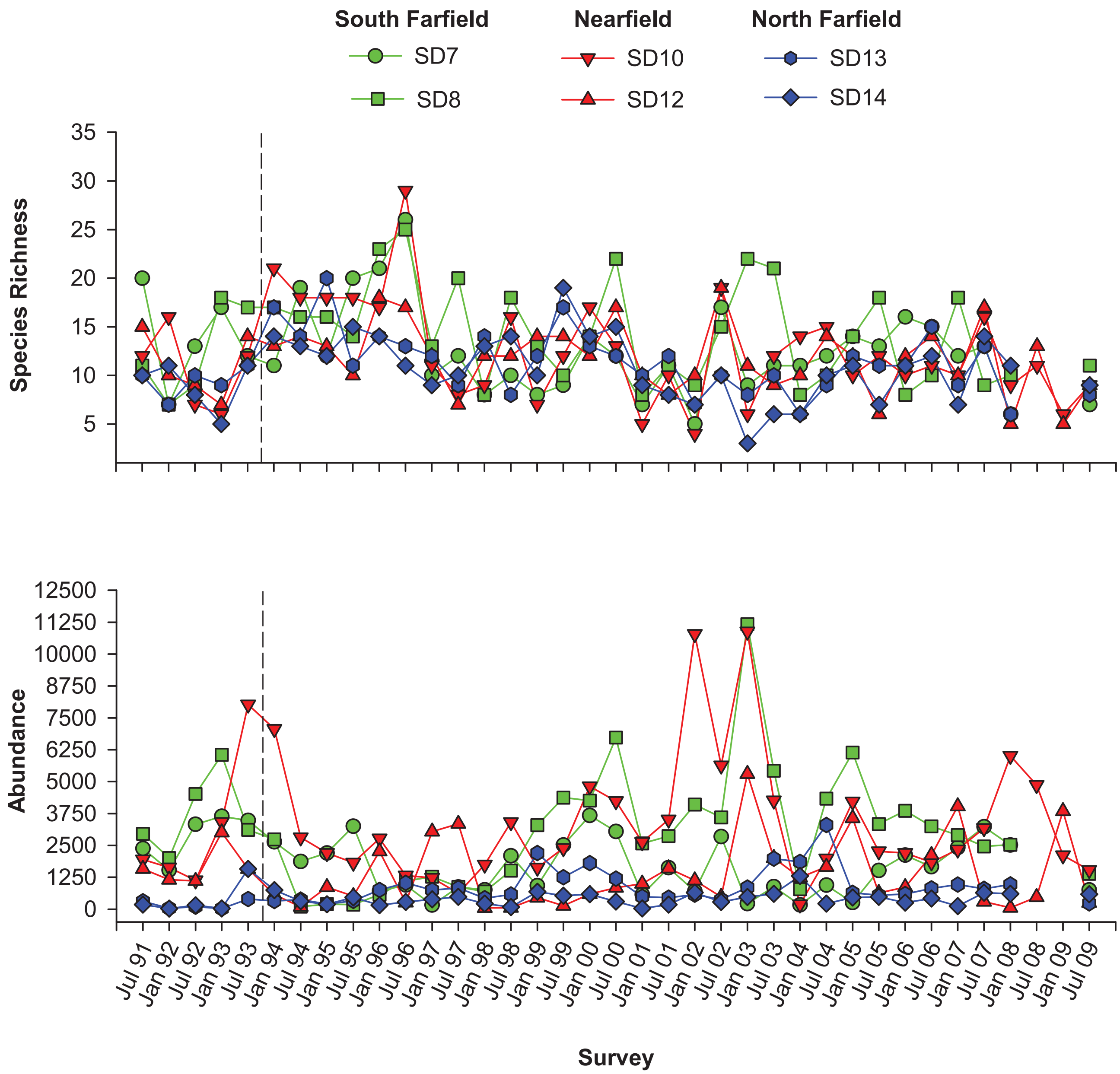


Figure 6.5

Species richness and abundance of megabenthic invertebrates collected at each PLOO trawl station between 1991 and 2009. Data are total number of species and total number of individuals per haul, respectively. Dashed line represents initiation of wastewater discharge.

of 2–1000 m. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., S.L. Moore, K.C. Schiff, S.B. Weisberg, D. Diener, J.K. Stull, A. Groce, J. Mubarak, C.L. Tang, and R. Gartman. (1998). Southern California Bight 1994 Pilot Project: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D.W. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Westminster, CA.

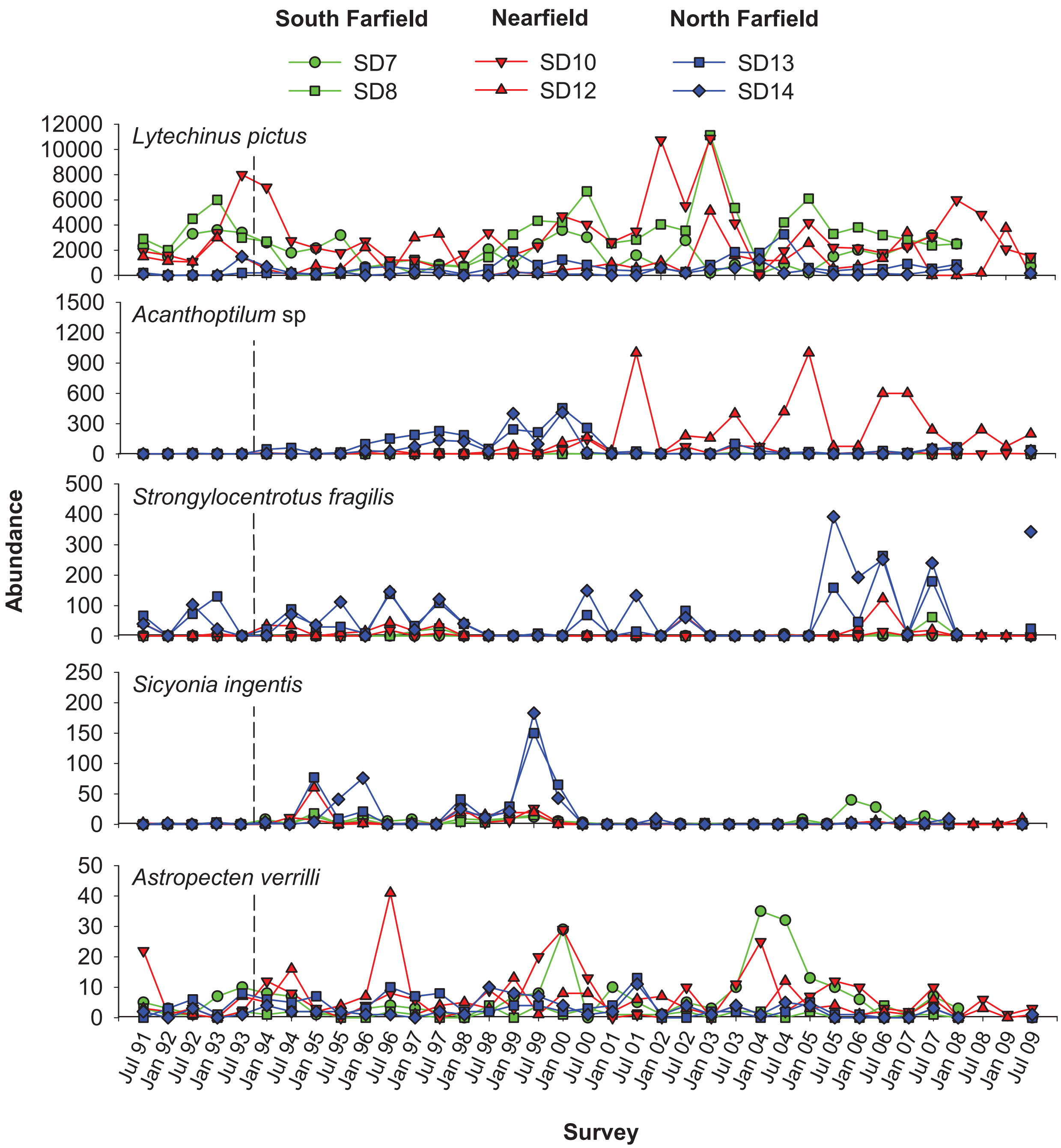


Figure 6.6
The five most abundant megabenthic species collected in the PLOO region from 1991 through 2009. Data are total number of individuals per haul. Dashed line represents initiation of wastewater discharge.

Allen, M.J., T. Mikel, D. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S. Walther, G. Deets, C. Cash, S. Watts, D.J. Pondella II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce, and J.L. Armstrong. (2007). Southern California Bight 2003 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Costa Mesa, CA.

Brusca, R.C. (1978). Studies on the cymothoid fish symbionts of the eastern Pacific (Crustacea: Cymothoidae). II. Systematics and biology of *Livoneca vulgaris* Stimpson 1857. Occassional Papers of the Allan Hancock Foundation. (New Series), 2: 1–19.

Brusca, R.C. (1981). A monograph on the Isopoda Cymothoidae (Crustacea) of the eastern Pacific. Zoological Journal of the Linnean Society, 73: 117–199.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R. and R.N. Gorley. (2006). Primer v6: User Manual/Tutorial. PRIMER-E: Plymouth.

Cross, J.N., J.N. Roney, and G.S. Kleppel. (1985). Fish food habitats along a pollution gradient. California Fish and Game, 71: 28–39.

Cross, J.N. and L.G. Allen. (1993). Chapter 9. Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eschmeyer, W.N. and E.S. Herald. (1998). A Field Guide to Pacific Coast Fishes of North America. Houghton and Mifflin Company, New York.

Helvey, M. and R.W. Smith. (1985). Influence of habitat structure on the fish assemblages associated with two cooling-water intake structures in southern California. Bulletin of Marine Science, 37: 189–199.

Karinen, J.B., B.L. Wing, and R.R. Straty. (1985). Records and sightings of fish and invertebrates in the eastern Gulf of Alaska and oceanic phenomena related to the 1983 El Niño event. In: W.S. Wooster and D.L. Fluharty (eds.). El Niño North: El Niño Effects in the Eastern Subarctic Pacific Ocean. Washington Sea Grant Program. p 253–267.

Murawski, S.A. (1993). Climate change and marine fish distribution: forecasting from historical analogy. Transactions of the American Fisheries Society, 122: 647–658.

[SCAMIT] The Southern California Association of Marine Invertebrate Taxonomists. (2008). A taxonomic listing of soft bottom macro- and megabenthic invertebrates from infaunal and epibenthic monitoring programs in the Southern California Bight; Edition 5. SCAMIT. San Pedro, CA.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

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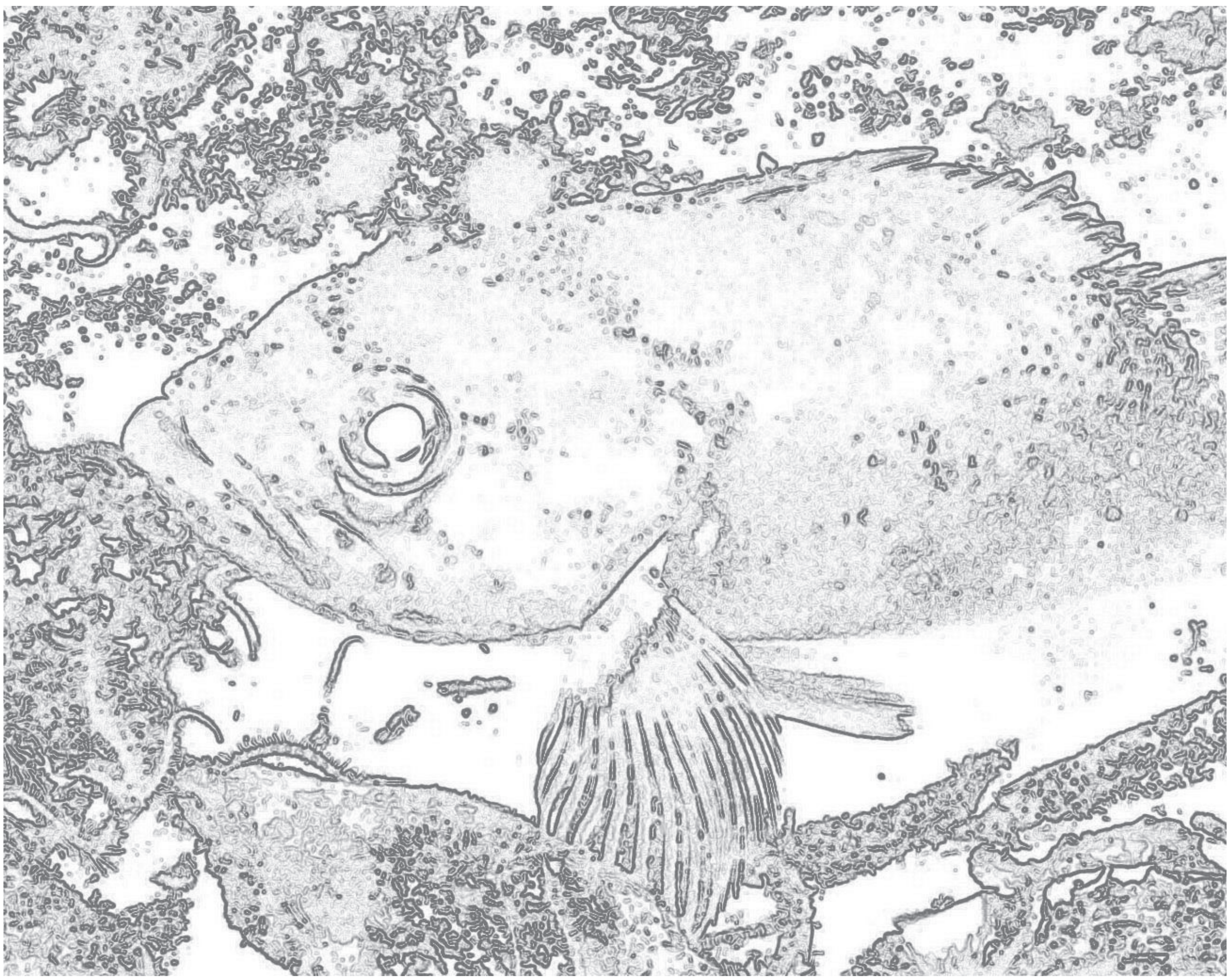
Chapter 7
Bioaccumulation of Contaminants in Fish Tissues



Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

INTRODUCTION

Bottom dwelling (i.e., demersal) fishes are collected as part of the Point Loma Ocean Outfall (PLOO) monitoring program to assess the accumulation of contaminants in their tissues. Bioaccumulation of contaminants in fish occurs through the biological uptake and retention of chemical contaminants derived via various exposure pathways (U.S. EPA 2000). The main exposure routes for demersal fishes include uptake of dissolved chemicals in seawater and the ingestion and assimilation of pollutants contained in different food sources (Rand 1995). Because of their proximity to seafloor sediments, these fish may also accumulate contaminants through ingestion of suspended particulates or sediments that contain pollutants. For this reason, the levels of many contaminants in the tissues of demersal fish are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the Point Loma monitoring program consists of two components: (1) liver tissues analyzed from trawl-caught fishes; (2) muscle tissues analyzed from fishes collected by hook and line (rig fishing). Species collected by trawling activities (see Chapter 6) are representative of the general demersal fish community with certain species targeted based on their overall prevalence and ecological significance. Analysis of liver tissues in these fish is especially important for assessing population level effects since this is the primary organ where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for capture by rig fishing represent species that are characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to seafood safety and public health issues. Consequently, muscle tissues are analyzed from these fishes because it is the tissue most often consumed by humans.

This chapter presents the results of all tissue analyses that were performed on fishes collected in the PLOO region during 2009. All liver and muscle samples were analyzed for contaminants as specified in the NPDES discharge permits that govern the PLOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program. NOAA initiated this program to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants thought to be of environmental concern (Lauenstein and Cantillo 1993).

Materials and Methods

Field Collection

Fishes were collected during October of 2009 from four trawl zones and two rig fishing stations (Figure 7.1). Each trawl zone represents an area centered around one or two specific sites. Zone 1 includes the area within a 1-km radius of stations SD10 and SD12 located just south and north of the PLOO, respectively. Zone 2 includes the area within a 1-km radius surrounding northern farfield stations SD13 and SD14. Zone 3 represents the area within a 1-km radius surrounding farfield station SD8, which is located south of the outfall near the LA-5 dredged materials disposal site. Zone 4 is the area within a 1-km radius surrounding farfield station SD7 located several kilometers south of the outfall near the non-active LA-4 disposal site. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for a description of collection methods). Efforts to collect targeted fish at the trawl stations were limited to five 10-minute (bottom time) trawls per zone. Fishes collected at the two rig fishing stations were caught within 1 km of the station coordinates using standard rod and reel procedures. Station RF1 is located within 1 km of the outfall and is considered the nearfield site. In contrast,

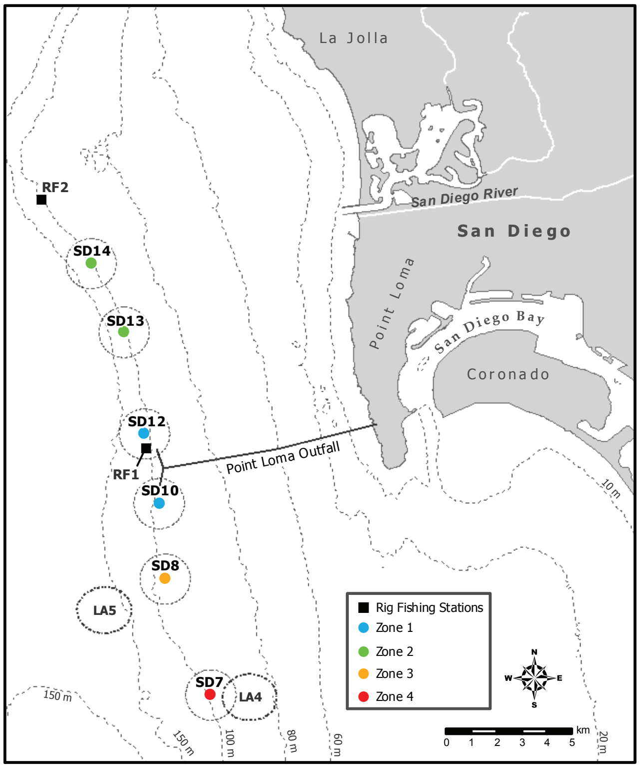


Figure 7.1
Otter trawl stations/zones and rig fishing stations for the Point Loma Ocean Outfall Monitoring Program. See text for description of zones.

Station RF2 is located about 11 km from the outfall and is considered farfield for the analyses herein. Fishing effort was limited to 5 hours per survey at each of the rig fishing stations.

Pacific sanddabs (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawling zones, while several different species of rockfish (*Sebastes* spp) were collected for analysis of muscle tissues at the rig fishing stations (see Table 7.1). The different species of rockfish analyzed included copper rockfish (*S. caurinus*), flag rockfish (*S. rubrivinctus*), greenspotted rockfish (*S. chlorostictus*), pink rockfish (*S. eos*), starry rockfish (*S. constellatus*), and vermilion rockfish (*S. miniatus*).

In order to facilitate the collection of sufficient tissue for subsequent chemical analysis, only fish ≥ 13 cm in standard length were retained. These fish were sorted into no more than three composite samples per zone/station, with each composite containing a minimum of three individuals. Composite samples were typically made up of a single species; the only exceptions were samples that consisted of mixed species of rockfish as indicated in Table 7.1. All fish collected were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

Table 7.1
Species of fish collected from each PLOO trawl zone or rig fishing station (RF1–RF2) during October 2009. Comp = composite; PS = Pacific sanddab; CRF = copper rockfish; VRF = vermilion rockfish; MRF = mixed rockfish.

Station/Zone	Comp 1	Comp 2	Comp 3
Zone 1	PS	PS	PS
Zone 2	PS	PS	PS
Zone 3	PS	PS	PS
Zone 4	PS	PS	PS
RF1	CRF	VRF	MRF [a]
RF2	VRF	VRF	MRF [b]

[a] Includes copper, flag, and pink rockfish.
[b] Includes greenspotted and starry rockfish.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (2004) for additional details. Prior to dissection, each fish was partially defrosted and cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of each fish were recorded (Appendix F.1). All dissections were carried out on Teflon® pads that were cleaned between samples. The tissues (liver or muscle) from each dissected fish were then placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory for analysis within 10 days of dissection.

Chemical constituents were measured on a wet weight basis, and included trace metals, chlorinated pesticides, and polychlorinated biphenyl compounds (PCBs) (see Appendix F.2). Metals were measured in units of mg/kg and are expressed herein as parts per million (ppm), while pesticides and PCBs were measured as µg/kg and expressed as parts per billion (ppb). This report includes estimated values for some parameters determined to be present in a sample with high confidence (i.e., peaks confirmed by mass-spectrometry), but that otherwise occurred at levels below the method detection limit (MDL). A detailed description of the protocols for chemical analyses is available in City of San Diego (2010a).

Data Analyses

Data summaries for each contaminant include detection rate, and the minimum, maximum and mean of all detected values by species. Totals for DDT, PCBs, hexachlorocyclohexanes (HCH), and chlordane were calculated as the sum of the detected constituents. For example, total DDT equals the sum of all DDT derivatives, while total PCB equals the sum of all individual congeners. The detected values for each of these individual constituents are listed in Appendix F.3. In order to address seafood safety and public health issues, the concentrations of contaminants found in fish muscle tissue samples collected in 2009 were also compared to state, national, and international limits and standards. These include: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, PCBs, and selenium (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (U.S. FDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human consumption (see Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (see Mearns et al. 1991).

Results and Discussion

Contaminants in Trawl-Caught Fishes

Nine different metals were detected in 100% of the liver tissue samples analyzed from trawl-caught Pacific sanddabs in 2009 (Table 7.2), including aluminum, arsenic, barium, cadmium, copper, iron, manganese, selenium, and zinc. Another eight metals were detected less frequently at rates between 8–92%. These included antimony, beryllium, chromium, mercury, nickel, silver, thallium, and tin. Lead was not detected in any of the liver samples collected during the year. Most of these metals occurred at concentrations ≤10 ppm. Exceptions included higher levels up to 18.8 ppm for aluminum, 93.1 ppm for iron, and 28.4 ppm for zinc. Comparisons of metal concentrations in fish samples collected from the nearfield (zone 1) stations to those located farther away in zones 2–4 revealed no clear pattern between contaminant loads in local fishes and proximity to

Table 7.2
Summary of metals, pesticides, total PCBs, and lipids in liver tissues of Pacific sanddabs collected at PLOO trawl zones during 2009. Data include detection rate (DR), as well as minimum (Min), maximum (Max), and mean detected concentrations ($n \leq 12$).

Parameter	DR (%)	Min	Max	Mean
Metals (ppm)				
Aluminum	100	5.81	18.80	12.18
Antimony	8	0.20	0.20	0.20
Arsenic	100	2.40	3.66	3.24
Barium	100	0.05	0.11	0.09
Beryllium	17	0.01	0.02	0.01
Cadmium	100	1.84	10.00	6.07
Chromium	58	0.11	0.28	0.19
Copper	100	2.53	8.50	5.58
Iron	100	31.10	93.10	62.17
Lead	0	—	—	—
Manganese	100	0.58	1.41	0.87
Mercury	92	0.04	0.31	0.12
Nickel	8	0.20	0.20	0.20
Selenium	100	0.71	1.24	1.04
Silver	8	0.06	0.06	0.06
Thallium	42	0.50	0.99	0.72
Tin	33	0.21	0.55	0.43
Zinc	100	16.70	28.40	23.27
Pesticides (ppb)				
HCB	100	3.70	7.70	6.28
Total DDT	100	244.80	994.30	405.58
Total PCB (ppb)	100	115.50	308.50	209.25
Lipids (% weight)	100	20.70	54.40	40.89

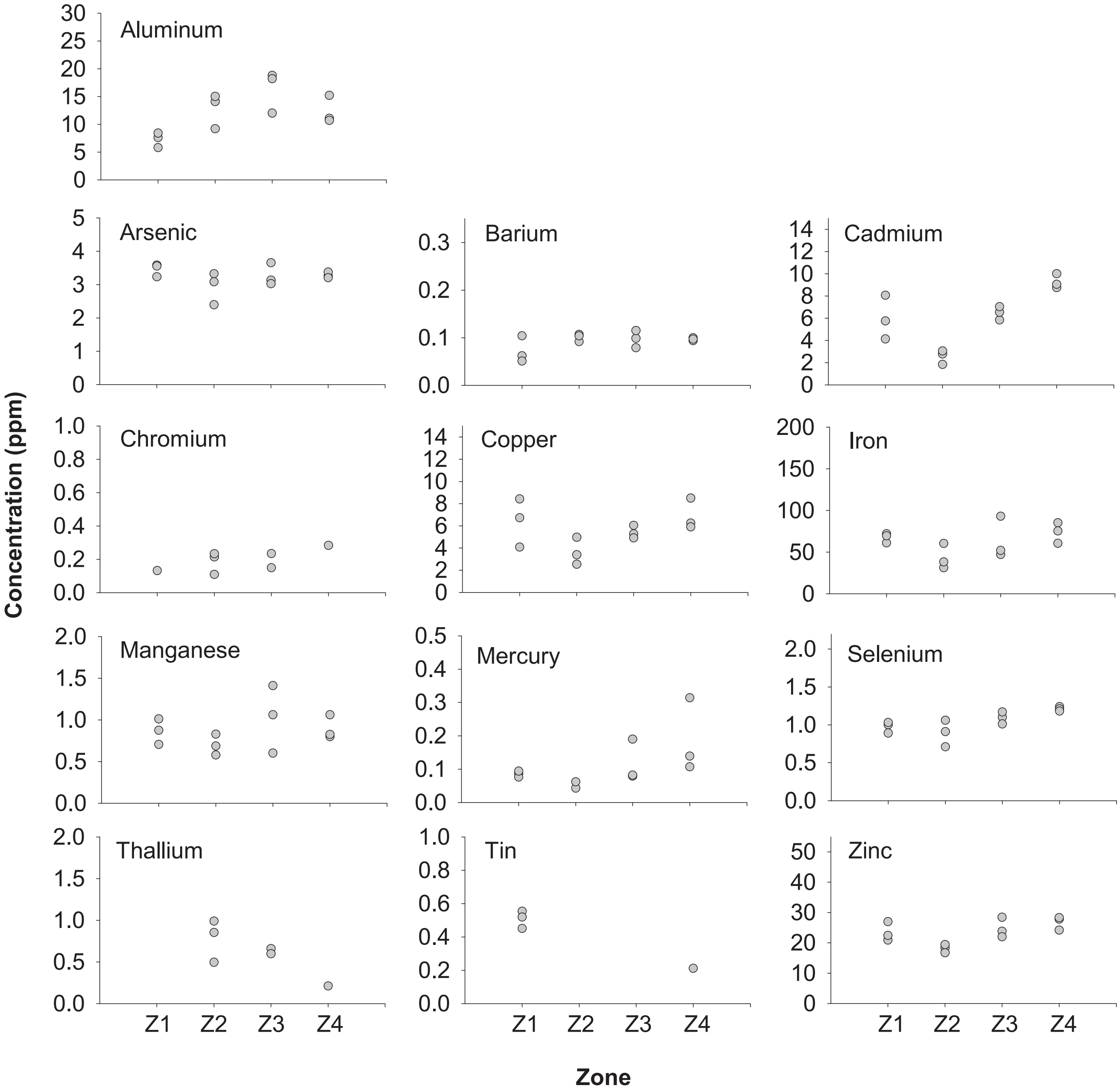


Figure 7.2
Concentrations of metals detected frequently (≥33%) in liver tissues of Pacific sanddabs collected from trawl zones Z1–Z4 off Point Loma during 2009. Missing values = non-detects.

the PLOO (Figure 7.2). Only concentrations of tin appeared to be higher in sanddab livers collected near the outfall than at the other monitoring sites, although even these higher levels were very low compared to values reported previously for the region (see City of San Diego 2009).

Only two chlorinated pesticides, DDT and hexachlorobenzene (HCB), were detected in trawl-caught Pacific sanddabs during 2009. Both pesticides were detected in all liver tissue samples but at concentrations substantially lower than their historical maximums (e.g., see City of San Diego 2007). For example, DDT was present in fish tissues at levels ranging between about 245–994 ppb, while HCB concentrations were lower at about 4–8 ppb (Table 7.2). Total DDT was composed primarily of p,p-DDE; this derivative accounted for 85–95% of the total DDT in all of the samples (Appendix F.3). Three other DDT derivatives also occurred in every sanddab liver sample (i.e., p,p-DDMU, p,p-DDD, and p,p-DDT), whereas a fourth (o,p-DDE) was detected in only one sample. All four of these derivatives were found at levels ≤25 ppb. Finally, no clear relationship could be determined between concentrations of these pesticides in fish tissues with a) proximity to the outfall discharge site (Figure 7.3), b) lipid content in fish, or c) the length or weight of the fish that comprised each composite.

Polychlorinated biphenyl compounds (PCBs) occurred in all liver tissue samples analyzed during 2009 (Table 7.2). Ten of the 25 PCB congeners that were detected occurred in 100% of the samples; these included PCB 70, PCB 99, PCB 101, PCB 110, PCB 138, PCB 149, PCB 151, PCB 153/168, PCB 180, and PCB 187 (Appendix F.3). Of these, PCB 153/168 and PCB138 occurred at the highest concentrations, with values ranging up to 65 and 40 ppb, respectively. Overall, total PCB concentrations were highly variable, ranging between about 116–309 ppb (Table 7.2). These values were an order of magnitude less than reported previously for the region (e.g., see City of San Diego 2007). Similar to that described above for pesticides, there was no clear relationship between PCB accumulation in fish with proximity to the outfall (Figure 7.3), lipid content, or size of the fish used in each composite.

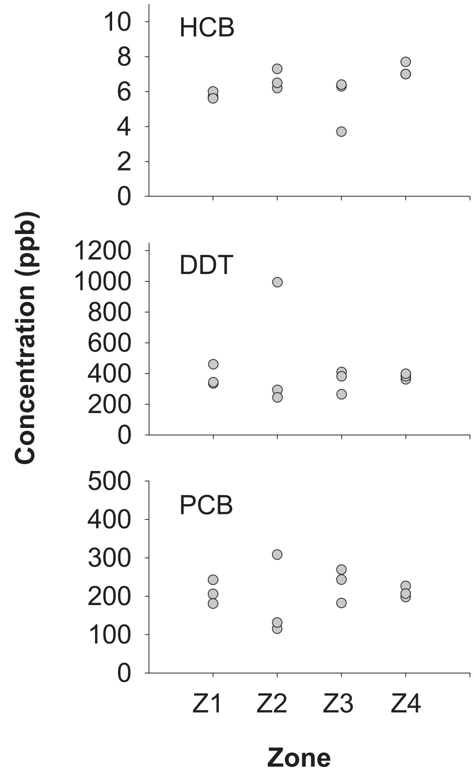


Figure 7.3
Concentrations of hexachlorobenzene (HCB), total DDT, and total PCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2009. Missing values = non-detects.

DDT was the only pesticide detected in the muscle tissues of fish collected in the Point Loma region during 2009. Total DDT (mostly p,p-DDE) was detected in 100% of the muscle samples but at relatively low concentrations ≤9 ppb (Table 7.4).

PCBs were also detected in every muscle tissue sample collected at the two rig fishing stations in 2009, with total PCB concentrations ranging from 0.8 to 14.8 ppb. PCB 153/168 was the most frequently detected congener, occurring in 100% of the samples. Other common congeners that were detected in at least 50% of the samples were PCB 101, PCB 118, PCB 138, and PCB 187 (Appendix F.3).

Contaminants in Fishes Collected by Rig Fishing

Aluminum, arsenic, barium, chromium, copper, mercury, selenium, and zinc occurred in 100% of the rockfish (*Sebastes* spp) muscle tissue samples collected at the two rig fishing stations in 2009 (Table 7.3). In addition to these eight metals, iron and silver were also detected, but less frequently at detection rates of 67%. The metals present in the highest concentrations were aluminum (up to 6.46 ppm), arsenic (up to 2.33 ppm), iron (up to 3.22 ppm), and zinc (up to 3.74 ppm). Concentrations of the remaining metals in fish muscle tissues were all <1 ppm.

Of the contaminants detected in fish muscle tissues during 2009, only the metals arsenic and selenium occurred in concentrations higher than median international standards, while mercury (as a proxy for methylmercury) and total PCB

Table 7.3

Summary of metals in rockfish muscle tissues collected at PLOO rig fishing stations during 2009. Data include the number of detected values (*n*), minimum (Min), maximum (Max), and mean detected concentrations per species, and the detection rate (DR) and maximum value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses; na = not available. OEHHA fish contaminant goals, U.S. FDA action limits (AL), and median international standards (IS) are given for parameters if available; bold values meet or exceed these standards. See Appendix F.2 for names of each metal represented by periodic table symbol.

	Al	**Sb**	**As**	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	**Ni**	**Se**	**Ag**	**Tl**	**Sn**	**Zn**
Copper rockfish (1)																		
n	1	0	1	1	0	0	1	1	0	0	0	1	0	1	0	0	0	1
Min	4.61	—	**1.92**	0.04	—	—	0.10	0.48	—	—	—	**0.256**	—	**0.500**	—	—	—	3.40
Max	4.61	—	**1.92**	0.04	—	—	0.10	0.48	—	—	—	**0.256**	—	**0.500**	—	—	—	3.40
Mean	4.61	—	**1.92**	0.04	—	—	0.10	0.48	—	—	—	**0.256**	—	**0.500**	—	—	—	3.40
Mixed rockfish (2)																		
n	2	0	2	2	0	0	2	2	1	0	0	2	0	2	1	0	0	2
Min	5.01	—	0.93	0.04	—	—	0.15	0.35	2.89	—	—	0.206	—	**0.480**	0.07	—	—	2.90
Max	5.03	—	**2.33**	0.04	—	—	0.17	0.58	2.89	—	—	**0.247**	—	**0.590**	0.07	—	—	3.74
Mean	5.02	—	**1.63**	0.04	—	—	0.16	0.47	2.89	—	—	**0.226**	—	**0.535**	0.07	—	—	3.32
Vermilion rockfish (3)																		
n	3	0	3	3	0	0	3	3	3	0	0	3	0	3	3	0	0	3
Min	5.80	—	1.22	0.04	—	—	0.11	0.32	2.19	—	—	0.075	—	**0.310**	0.05	—	—	2.87
Max	6.46	—	**2.33**	0.04	—	—	0.12	0.50	3.22	—	—	**0.223**	—	**0.430**	0.07	—	—	3.29
Mean	6.02	—	**1.63**	0.04	—	—	0.12	0.38	2.66	—	—	0.146	—	**0.388**	0.06	—	—	3.03
All Species:																		
DR (%)	100	0	100	100	0	0	100	100	67	0	0	100	0	100	67	0	0	100
Max	6.46	—	**2.33**	0.04	—	—	0.17	0.58	3.22	—	—	**0.256**	—	**0.590**	0.07	—	—	3.74
OEHHA	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL*	na	na	na	na	na	na	na	na	na	na	na	1.0	na		na	na	na	na
IS*	na	na	1.4	na	na	na	1	20	na	na	na	0.5	na	0.3	na	na	na	70

*From Mearns et al. 1991. U.S. FDA action limits for mercury and all international standards are for shellfish, but are often applied to fish.

Table 7.4

Summary of total DDT, total PCB, and lipids in rockfish muscle tissues collected at PLOO rig fishing stations during 2009. Data include number of detected values (*n*), minimum (Min), maximum (Max), and mean detected concentrations per species, and the detection rate (DR) and maximum value for all species. Number of samples per species is indicated in parentheses; na = not available. OEHHA fish contaminant goals, U.S. FDA action limits (AL), and median international standards (IS) are given for parameters if available; bold values meet or exceed these standards.

	tDDT (ppb)	tPCB (ppb)	Lipids (% weight)
Copper rockfish (1)			
n	1	1	1
Min	9.0	**4.1**	0.7
Max	9.0	**4.1**	0.7
Mean	9.0	**4.1**	0.7
Mixed rockfish (2)			
n	2	2	2
Min	3.6	0.8	0.7
Max	8.5	**14.8**	0.7
Mean	6.0	**7.8**	0.7
Vermilion rockfish (3)			
n	3	3	3
Min	4.6	0.8	0.6
Max	8.2	2.6	0.9
Mean	6.0	1.5	0.7
All Species:			
DR	100	100	100
Max	9.0	**14.8**	0.9
OEHHA	21	3.6	na
AL*	5000	na	na
IS*	5000	na	na

* From Mearns et al. 1991. U.S. FDA action limits and all international standards (IS) are for shellfish, but are often applied to fish.

exceeded OEHHA fish contaminant goals. Levels of DDT did not exceed either of these standards, and none of the contaminants evaluated exceeded U.S. FDA action limits. Exceedances for arsenic, mercury, and selenium occurred in copper rockfish, vermilion rockfish, and "mixed" rockfish samples, while exceedances for total PCB occurred only in copper and "mixed" rockfish samples.

In addition to addressing seafood safety and public health issues, spatial patterns were analyzed for DDT and total PCB, as well as for all metals that occurred frequently in rockfish muscle tissues (Figure 7.4). Overall, concentrations of DDT, PCB, and various metals in the muscles of fishes captured at the two rig fishing stations were fairly similar, which suggests that there was no relationship with proximity to the outfall. However, comparisons of contaminant loads in fishes from these stations should be considered with caution since different species were collected at the two sites, and the bioaccumulation of contaminants may differ between species because of differences in physiology, diet, migration habits, and/or other large scale movements that affect contaminant exposure and uptake. This problem may be minimal in the Point Loma region as all rockfish sampled in 2009 are bottom dwelling tertiary carnivores with similar life history characteristics. Thus, these fishes are likely to have similar mechanisms of exposure to and uptake of contaminants (e.g., direct contact with sediments, similar food sources). However, many rockfish such as those reported herein are known to traverse large areas (M. Love, pers. comm.), and therefore they may also be exposed to contaminants in other areas.

Summary and Conclusions

Several trace metals, the pesticides DDT and HCB, and PCBs were detected in Pacific sanddab liver tissue samples collected from the PLOO region during 2009. Many of the same contaminants were also detected in muscle tissues of several species of rockfish (*Sebastes* spp) sampled during the year, although often less frequently and/or in lower concentrations. Tissue contaminant loads varied widely in fishes collected within and among stations. However, all contaminant levels were within the range of values reported previously for Southern California Bight (SCB) fishes by Mearns et al. (1991) and Allen et al. (1998). In addition, concentrations of these contaminants were generally similar to those reported previously for the Point Loma region (e.g., City of San Diego 2003, 2007), as well as for other long-term monitoring sites for the South Bay Ocean Outfall monitoring area

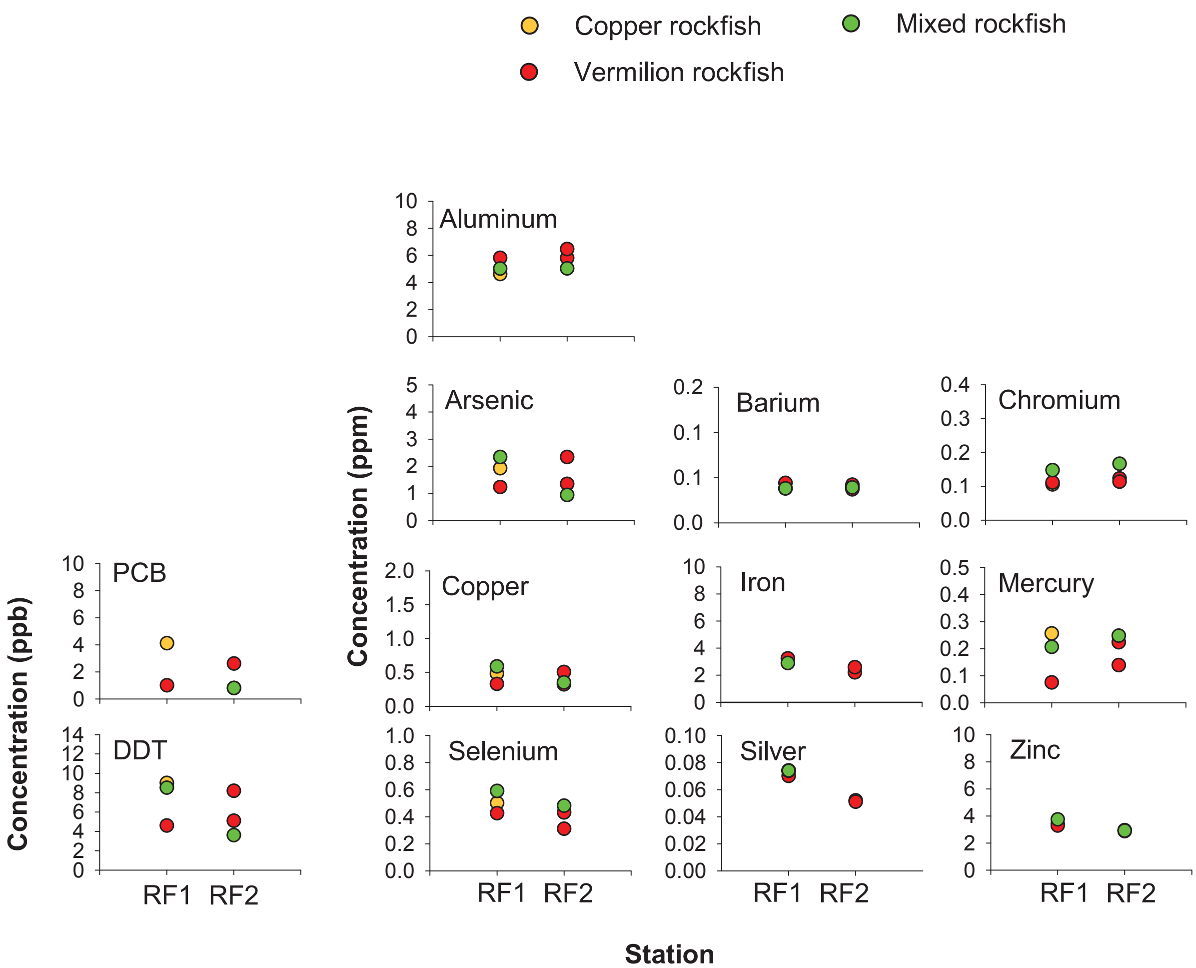


Figure 7.4
Concentrations of total PCB, total DDT, and metals detected frequently (≥67%) in muscle tissues of rockfishes collected from each PLOO rig fishing station during 2009. Missing values = non-detects.

(e.g., City of San Diego 2010b). Further, while some muscle tissue samples from sport fish collected off Point Loma had arsenic and selenium concentrations above the median international standard for shellfish, and some had mercury and PCB levels that exceeded OEHHA fish contaminant goals, concentrations of mercury and DDT were still below the U.S. FDA consumption limits for humans.

The presence of various trace metals and chlorinated hydrocarbons in the tissues of fish captured off Point Loma may be due to multiple factors. For example, Mearns et al. (1991) described the distribution of contaminants such as arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the marine environment, although little information is available on background levels in fish tissues. In addition, Brown et al. (1986) concluded that no areas of the SCB are sufficiently free of chemical contaminants to be considered true reference sites. This conclusion has been supported by more recent work regarding PCBs and DDT (e.g., Allen et al. 1998, 2002).

Other factors that affect the accumulation and distribution of contaminants include the physiology and life history traits of different species of fish (see Groce 2002 and references therein). For example, exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). Fishes may also be exposed to contaminants in an area that is highly contaminated and then move into another area that is not. In addition, intra-specific differences in feeding habits, age, reproductive status, and gender can affect the amount of contaminants that a fish will retain in its tissues (e.g., Connell 1987, Evans et al. 1993).

Overall, there was no evidence that fishes collected in 2009 were contaminated by the discharge of wastewater from the PLOO. Concentrations of most contaminants were similar across zones or stations, and no clear relationship relevant to the outfall was evident. These results are consistent with findings of two recent assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, Parnell et al. 2008). Finally, there were no other indications of adverse fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

Literature Cited

Allen, M.J., S.L. Moore, K.C. Schiff, D. Diener, S.B. Weisberg, J.K. Stull, A. Groce, E. Zeng, J. Mubarak, C.L. Tang, R. Gartman, and C.I. Haydock. (1998). Assessment of demersal fish and megabenthic invertebrate assemblages on the mainland shelf of Southern California in 1994. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Brown, D.A., R.W. Gossett, G.P. Hershelman, C.G. Word, A.M. Westcott, and J.N. Cross. (1986). Municipal wastewater contamination in the Southern California Bight: Part I — Metal and Organic Contaminants in Sediments and Organisms. Marine Environmental Research, 18: 291–310.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2002. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Quality Assurance Manual, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Appendix F. Bioaccumulation Assessment. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010a). 2009 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Connell, D.W. (1987). Age to PCB concentration relationship with the striped bass (*Morone saxatilis*) in the Hudson River and Long Island Sound. Chemosphere, 16: 1469–1474.

Evans, D.W., D.K. Dodoo, and P.J. Hanson. (1993). Trace element concentrations in fish livers: Implications of variations with fish size in pollution monitoring. Marine Pollution Bulletin, 26: 329–334.

Groce, A.K. (2002). Influence of life history and lipids on the bioaccumulation of organochlorines in demersal fishes. Master's thesis. San Diego State University. San Diego, CA.

Klasing, S. and R. Brodberg (2008). Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA.

Lauenstein, G.G. and A.Y. Cantillo, eds. (1993). Sampling and Analytical Methods of the NOAA National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984–1992: Vol. I–IV. Technical Memorandum. NOS ORCA 71. NOAA/NOS/ORCA, Silver Spring, MD.

Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. (1991). Contaminant Trends in the Southern California Bight: Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62. Seattle, WA.

Otway, N. (1991). Bioaccumulation studies on fish: choice of species, sampling designs, problems and implications for environmental management. In: A.G. Miskiewicz (ed.). Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts, and Bioaccumulation of Contaminants in Aquatic Environments. Australian Marine Science Association, Inc./Water Board.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin 56: 1992–2002.

Rand, G.M., ed. (1995). Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment. 2nd ed. Taylor and Francis, Washington, D.C.

Schiff, K. and M.J. Allen. (1997). Bioaccumulation of chlorinated hydrocarbons in livers of flatfishes from the Southern California Bight. In: S.B. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project Annual Report 1995–1996. Southern California Coastal Water Research Project, Westminster, CA.

[U.S. EPA] United States Environmental Protection Agency. (2000). Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment. Status and Needs. EPA-823-R-00-001. U.S. Environmental Protection Agency.

Glossary

GLOSSARY

Absorption
The movement of dissolved substances (e.g., pollution) into cells by diffusion.

Adsorption
The adhesion of dissolved substances to the surface of sediment or on the surface of an organism (e.g., a flatfish).

Anthropogenic
Made and introduced into the environment by humans, especially pertaining to pollutants.

Assemblage
An association of interacting populations in a given habitat (e.g., an assemblage of benthic invertebrates on the ocean floor).

BACIP Analysis
An analytical tool used to assess environmental changes caused by the effects of pollution. A statistical test is applied to data from matching pairs of control and impacted sites before and after an event (i.e., initiation of wastewater discharge) to test for significant change. Significant differences are generally interpreted as being the result of the environmental change attributed to the event. Variation that is not significant reflects natural variation.

Benthic
Pertaining to the environment inhabited by organisms living on or in the ocean bottom.

Benthos
Living organisms (e.g., algae and animals) associated with the sea bottom.

Bioaccumulation
The process by which a chemical becomes accumulated in tissue over time through direct intake of contaminated water, the consumption of contaminated prey, or absorption through the skin or gills.

Biota
The living organisms within a habitat or region.

BOD
Biochemical oxygen demand (BOD) is the amount of oxygen consumed (through biological or chemical processes) during the decomposition of organic material contained in a water or sediment sample. It is a measure for certain types of organic pollution, such that high BOD levels suggest elevated levels of organic pollution.

BRI
The benthic response index (BRI) measures levels of environmental disturbance by assessing the condition of a benthic assemblage. The index was based on organisms found in the soft sediments of the Southern California Bight (SCB).

CFU
The colony-forming unit (CFU) is the bacterial cell or group of cells which reproduce on a plate and result in a visible colony that can be quantified as a measurement of density; it is often used to estimate bacteria concentrations in ocean water.

Control site
A geographic location that is far enough from a known pollution source (e.g., ocean outfall) to be considered representative of an undisturbed environment. Data collected from control sites are used as a reference and compared to impacted sites.

COP
The California Ocean Plan (COP) is California's ocean water quality control plan. It limits wastewater discharge and implements ocean monitoring. Federal law requires the plan to be reviewed every three years.

Crustacea
A group (subphylum) of marine invertebrates characterized by jointed legs and an exoskeleton (e.g., crabs, shrimp, and lobster).

CTD
A device consisting of a group of sensors that continually measure various physical and chemical properties such as conductivity (a proxy for salinity), temperature, and pressure (a proxy for depth) as it

is lowered through the water. These parameters are used to assess the physical ocean environment.

Demersal
Organisms living on or near the bottom of the ocean and capable of active swimming.

Dendrogram
A tree-like diagram used to represent hierarchal relationships from a multivariate analysis where results from several monitoring parameters are compared among sites.

Detritus
Particles of organic material from decomposing organisms. Used as an important source of nutrients in a food web.

Diversity
A measurement of community structure which describes the abundances of different species within a community, taking into account their relative rarity or commonness.

Dominance
A measurement of community structure that describes the minimum number of species accounting for 75% of the abundance in each grab.

Echinodermata
A group (phylum) of marine invertebrates characterized by the presence of spines, a radially symmetrical body, and tube feet (e.g., sea stars, sea urchins, and sea cucumbers).

Effluent
Wastewater that flows out of a sewer, treatment plant outfall, or other point source and is discharged into a water body (e.g. ocean, river).

FIB
Fecal indicator bacteria (FIB) are the bacteria (total coliform, fecal coliform, and enterococcus) measured and evaluated to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall.

Halocline
A vertical zone of water in which the salinity changes rapidly with depth.

Impact site
A geographic location that has been altered by the effects of a pollution source, such as a wastewater outfall.

Indicator species
Marine invertebrates whose presence in the community reflects the health of the environment. The loss of pollution-sensitive species or the introduction of pollution-tolerant species can indicate anthropogenic impact.

Infauna
Animals living in the soft bottom sediments usually burrowing or building tubes within.

Invertebrate
An animal without a backbone (e.g., sea star, crab, and worm).

Kurtosis
A measure that describes the shape (i.e., peakedness or flatness) of distribution relative to a normal distribution (bell shape) curve. Kurtosis can indicate the range of a data set, and is used herein to describe the distribution of particle sizes within sediment samples.

Macrobenthic invertebrate
Epifaunal or infaunal benthic invertebrates that are visible with the naked eye. This group typically includes those animals larger than meiofauna and smaller than megafauna. These animals are collected in grab samples from soft-bottom marine habitats and retained on a 1-mm mesh screen.

MDL
The EPA defines MDL (method detection limit) as "the minimum concentration that can be determined with 99% confidence that the true concentration is greater than zero."

Megabenthic invertebrate
A larger, usually epibenthic and motile, bottom-dwelling animal such as a sea urchin, crab, or snail. These animals are typically collected by otter trawl nets with a minimum mesh size of 1 cm.

Mollusca
A taxonomic group (phylum) of invertebrates characterized as having a muscular foot, visceral mass, and a shell. Examples include snails, clams, and octupuses.

Motile
Self-propelled or actively moving.

Niskin bottle
A long plastic tube allowing seawater to pass through until the caps at both ends are triggered to close from the surface. They often are arrayed with several others in a rosette sampler to collect water at various depths.

Non-point source
Pollution sources from numerous points, not a specific outlet, generally carried into the ocean by storm water runoff.

NPDES
The National Pollutant Discharge Elimination System (NPDES) is a federal permit program that controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Ophiuroidea
A taxonomic group (class) of echinoderms that comprises the brittle stars. Brittle stars usually have five long, flexible arms and a central disk-shaped body.

PAHs
The USGS defines polycyclic aromatic hydrocarbons (PAHs) as, "hydrocarbon compounds with multiple benzene rings. PAHs are typical components of asphalts, fuels, oils, and greases."

PCBs
The EPA defines polychlorinated biphenyls (PCBs) as, "a category, or family, of chemical compounds formed by the addition of chlorine (C_{12}) to biphenyl ($C_{12}H_{10}$), which is a dual-ring structure comprising two 6-carbon benzene rings linked by a single carbon-carbon bond."

PCB Congeners
The EPA defines a PCB congener as, "one of the 209 different PCB compounds. A congener may have between one and 10 chlorine atoms, which may be located at various positions on the PCB molecule."

Phi
The conventional unit of sediment size based on the log of sediment grain diameter. The larger the phi number, the smaller the grain size.

Plankton
Animal and plant-like organisms, usually microscopic, that are passively carried by ocean currents.

PLOO
The Point Loma Ocean Outfall (PLOO) is the underwater pipe originating at the Point Loma Wastewater Treatment Plant and used to discharge treated wastewater. It extends 7.2 km (4.5 miles) offshore and discharges into 96 m (320 ft) of water.

Point source
Pollution discharged from a single source (e.g., municipal wastewater treatment plant, storm drain) to a specific location through a pipe or outfall.

Polychaeta
A taxonomic group (class) of invertebrates characterized as having worm-like features, segments, and bristles or tiny hairs. Examples include bristle worms and tube worms.

Pycnocline
A depth zone in the ocean where sea water density changes rapidly with depth and typically is associated with a decline in temperature and increase in salinity.

Recruitment
The retention of young individuals into the adult population in an open ocean environment.

Relict sand
Coarse reddish-brown sand that is a remnant of a pre-existing formation after other parts have disappeared. Typically originating from land and transported to the ocean bottom through erosional processes.

Rosette sampler
A device consisting of a round metal frame housing a CTD in the center and multiple bottles (see Niskin bottle) arrayed about the perimeter. As the instrument is lowered through the water column, continuous measurements of various physical and chemical parameters are recorded by the CTD. Discrete water samples are captured at desired depths by the bottles.

SBOO
The South Bay Ocean Outfall (SBOO) is the underwater pipe originating at the International Wastewater Treatment Plant and used to discharge treated wastewater. It extends 5.6 km (3.5 miles) offshore and discharges into about 27 m (90 ft) of water.

SBWRP
The South Bay Water Reclamation Plant (SBWRP) provides local wastewater treatment services and reclaimed water to the South Bay. The plant began operation in 2002 and has a wastewater treatment capacity of 15 million gallons a day.

SCB
The Southern California Bight (SCB) is the geographic region that stretches from Point Conception, U.S.A. to Cabo Colnett, Mexico and encompasses nearly 80,000 km^2 of coastal land and sea.

Shell hash
Sediments composed of shell fragments.

Skewness
A measure of the lack of symmetry in a distribution or data set. Skewness can indicate where most of the data lies within a distribution. It can be used to describe the distribution of particle sizes within sediment grain size samples.

Sorting
The range of grain sizes that comprises marine sediments. Also refers to the process by which sediments of similar size are naturally segregated during transport and deposition according to the velocity and transporting medium. Well sorted sediments are of similar size (such as desert sand), while poorly sorted sediments have a wide range of grain sizes (as in a glacial till).

Species richness
The number of species per sample or unit area. A metric used to evaluate the health of macro-benthic communities.

Standard length
The measurement of a fish from the most forward tip of the body to the base of the tail (excluding the tail fin rays). Fin rays can sometimes be eroded by pollution or preservation so measurement that includes them (i.e., total length) is considered less reliable.

Thermocline
The zone in a thermally stratified body of water that separates warmer surface water from colder deep water. At a thermocline, temperature changes rapidly over a short depth.

Tissue burden
The total amount of measured chemicals that are present in the tissue (e.g. fish muscle).

Transmissivity
A measure of water clarity based upon the ability of water to transmit light along a straight path. Light that is scattered or absorbed by particulates (e.g., plankton, suspended solid materials) decreases the transmissivity (or clarity) of the water.

Upwelling
The movement of nutrient-rich and typically cold water from the depths of the ocean to the surface waters.

USGS
The United States Geological Survey (USGS) provides geologic, topographic, and hydrologic information on water, biological, energy, and mineral resources.

Van Dorn bottle
A water sampling device made of a plastic tube open at both ends that allows water to flow through. Rubber caps at the tube ends can be triggered to close underwater to collect water at a specified depth.

Van Veen grab
A mechanical device designed to collect ocean sediment samples. The device consists of a pair of hinged jaws and a release mechanism that allows the opened jaws to close and entrap a 0.1 m^2 sediment sample once the grab touches bottom.

Wastewater
A mixture of water and waste materials originating from homes, businesses, industries, and sewage treatment plants.

ZID
The zone of initial dilution (ZID) is the region of initial mixing of the surrounding receiving waters with wastewater from the diffuser ports of an outfall. This area includes the underlying seabed. In the ZID, the environment is chronically exposed to pollutants and often is the most impacted.

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Appendices

Appendix A

Supporting Data

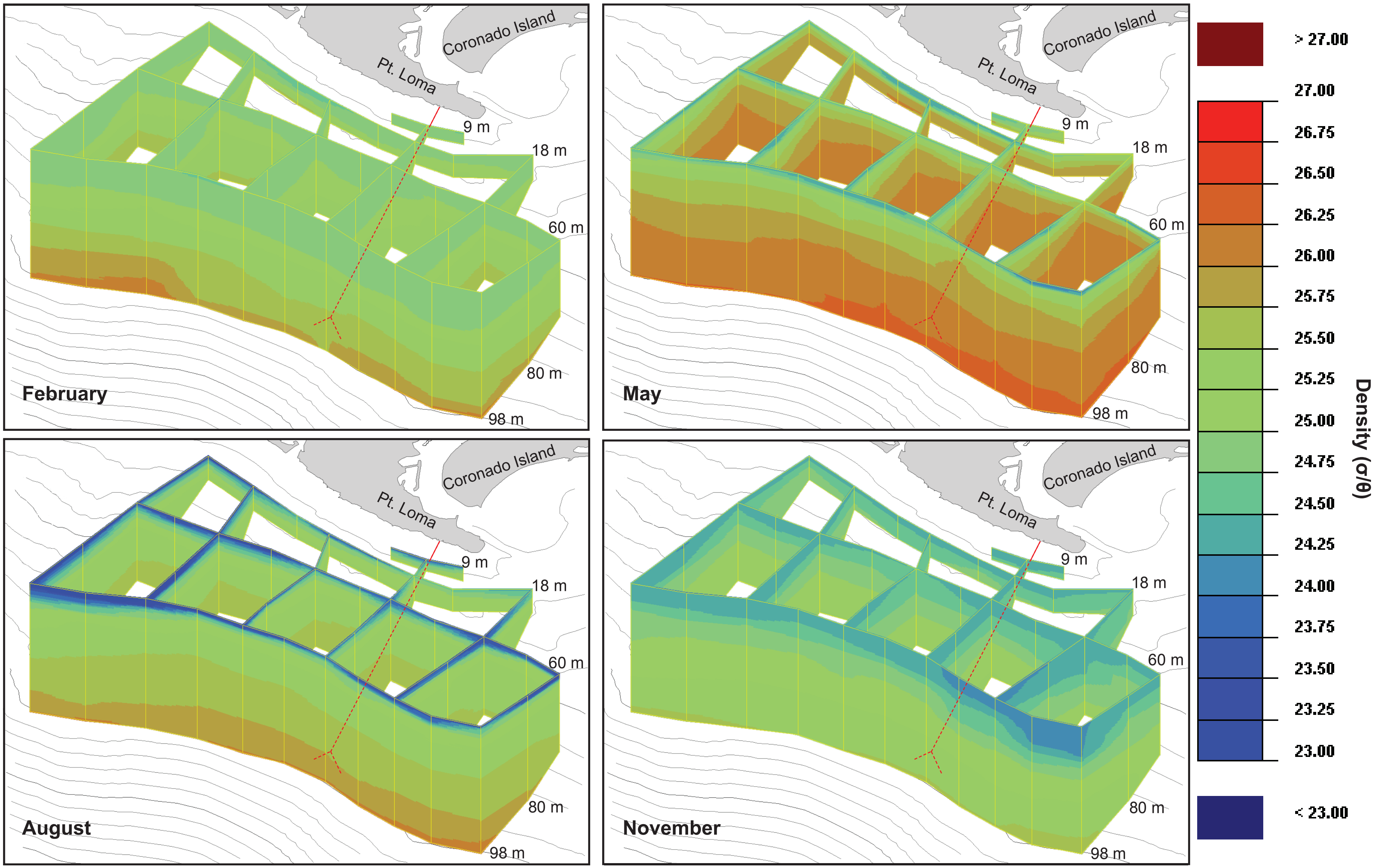
2009 PLOO Stations

Oceanographic Conditions

Appendix A.1

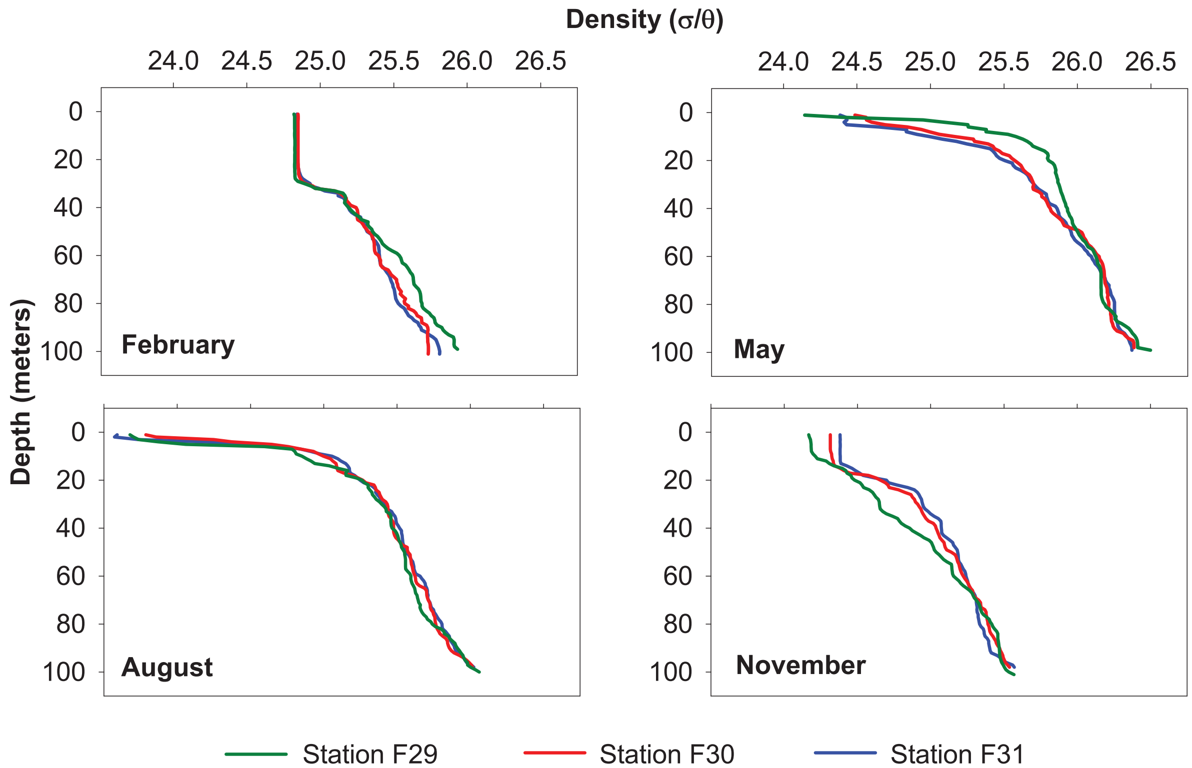
Summary of the dates CTD casts were conducted during 2009. Stations were sampled quarterly over four days. This included 12 stations sampled on the day designated “North WQ” (stations F02, F03, F11–F14, F23–F25, F34–F36), 12 stations sampled on the day designated “Mid WQ” (stations F07–F10, F19–F22, F30–F33), 12 stations sampled on the day designated “South WQ” (stations F01, F04–F06, F15–F18, F26–F29), and 8 stations sampled on the day designated “Kelp WQ” (stations A1, A6, A7, C4-C8).

	2009 Sample Dates			
Sample Group	**February**	**May**	**August**	**November**
North WQ	13	4	3	2
Mid WQ	10	5	5	4
South WQ	12	6	6	5
Kelp WQ	11	8	8	7



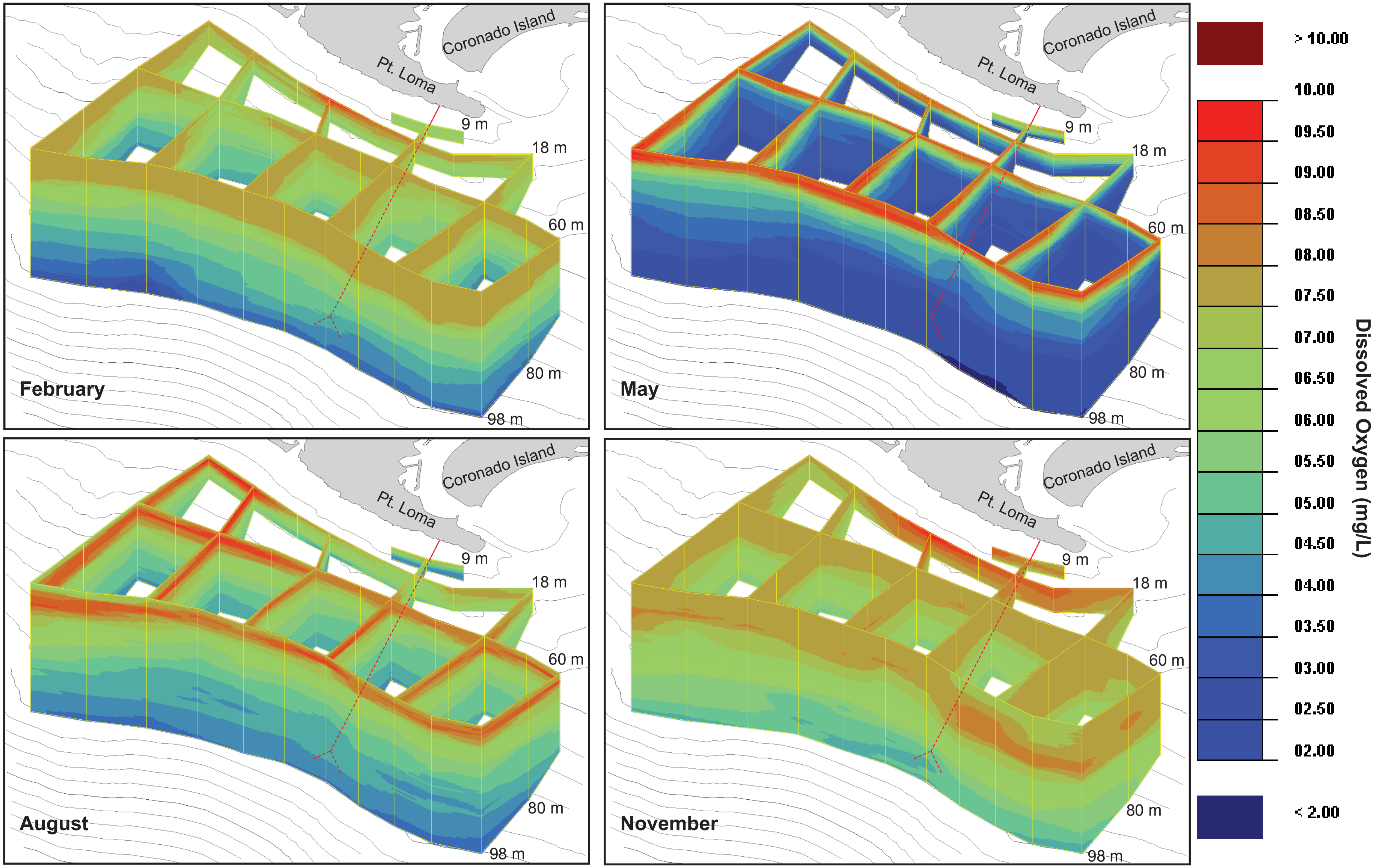
Appendix A.2

Ocean density recorded in 2009 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.



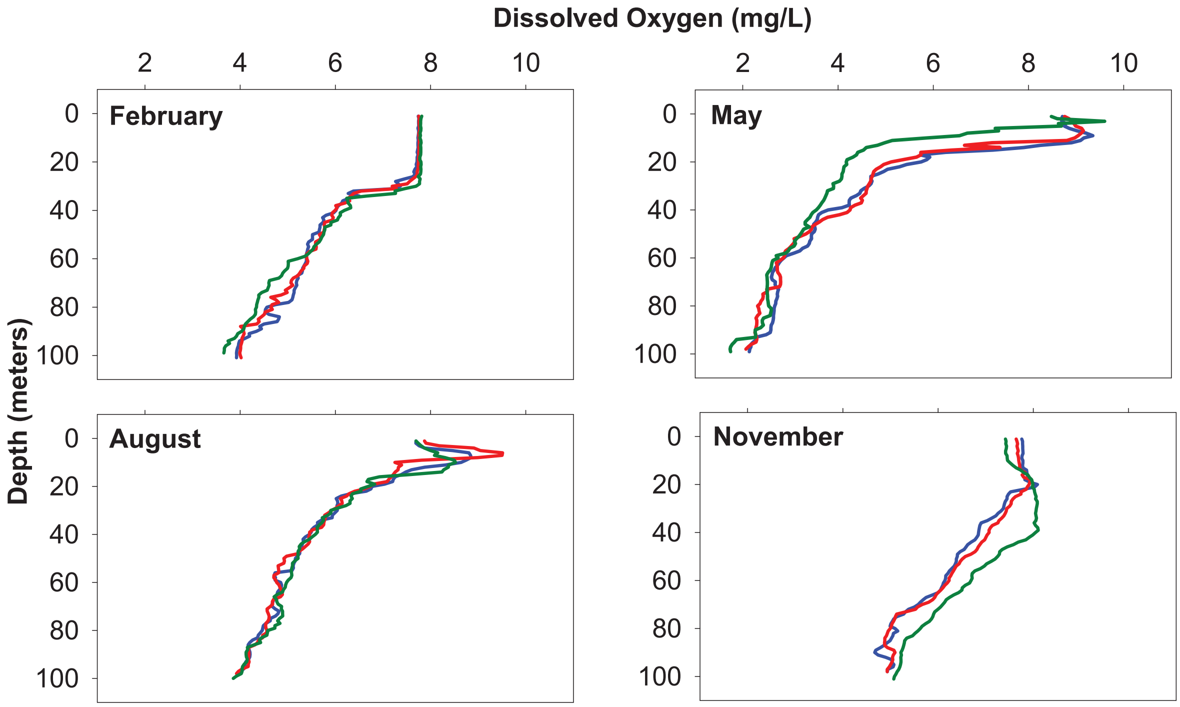
Appendix A.3

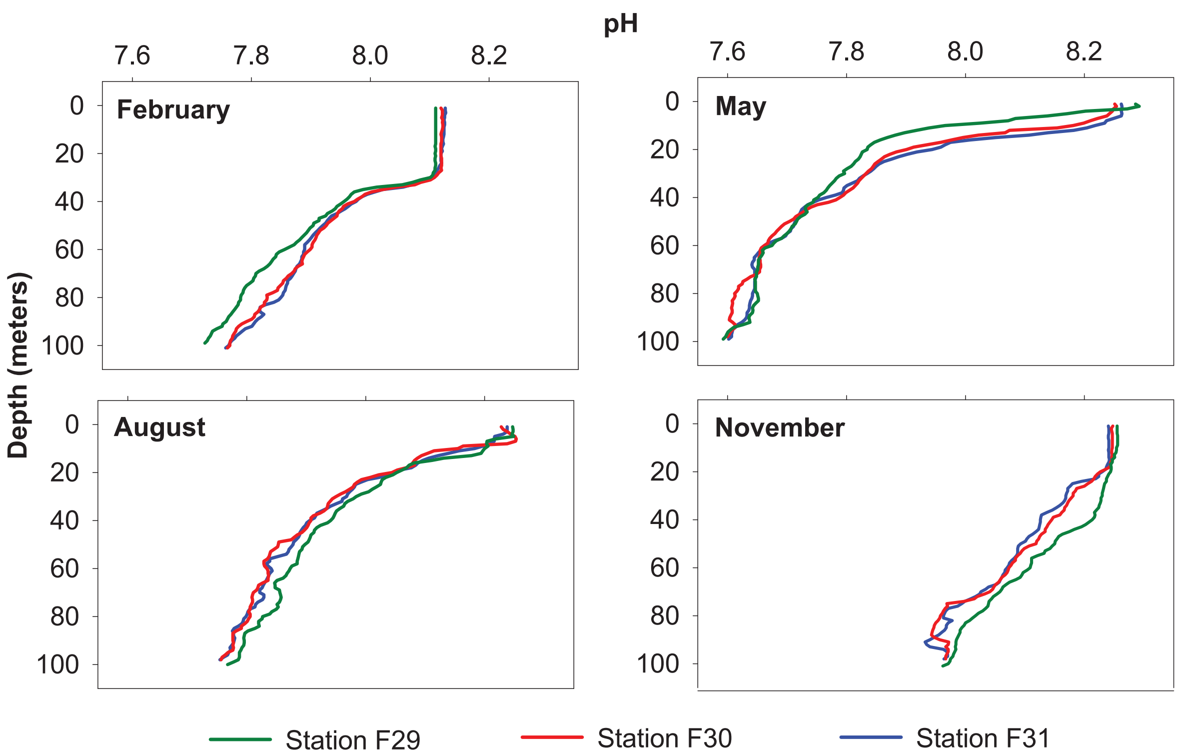
Vertical profiles of density for PLOO stations F29, F30, and F31 during 2009.



Appendix A.4

Concentrations of dissolved oxygen recorded in 2009 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.





Appendix A.5

Vertical profiles of dissolved oxygen and pH for PLOO stations F29, F30, and F31 during 2009.

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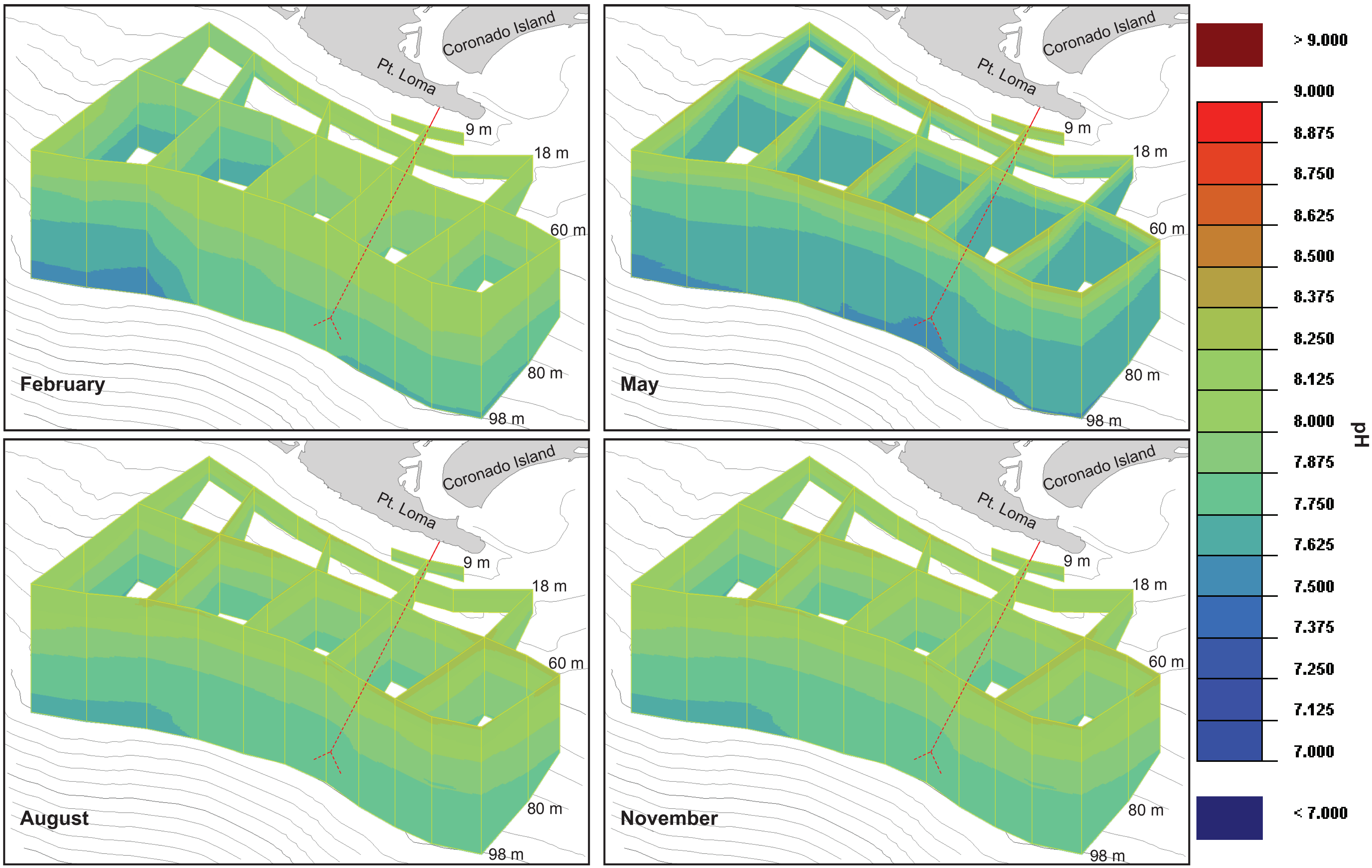

Appendix A.6

Levels of pH recorded in 2009 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

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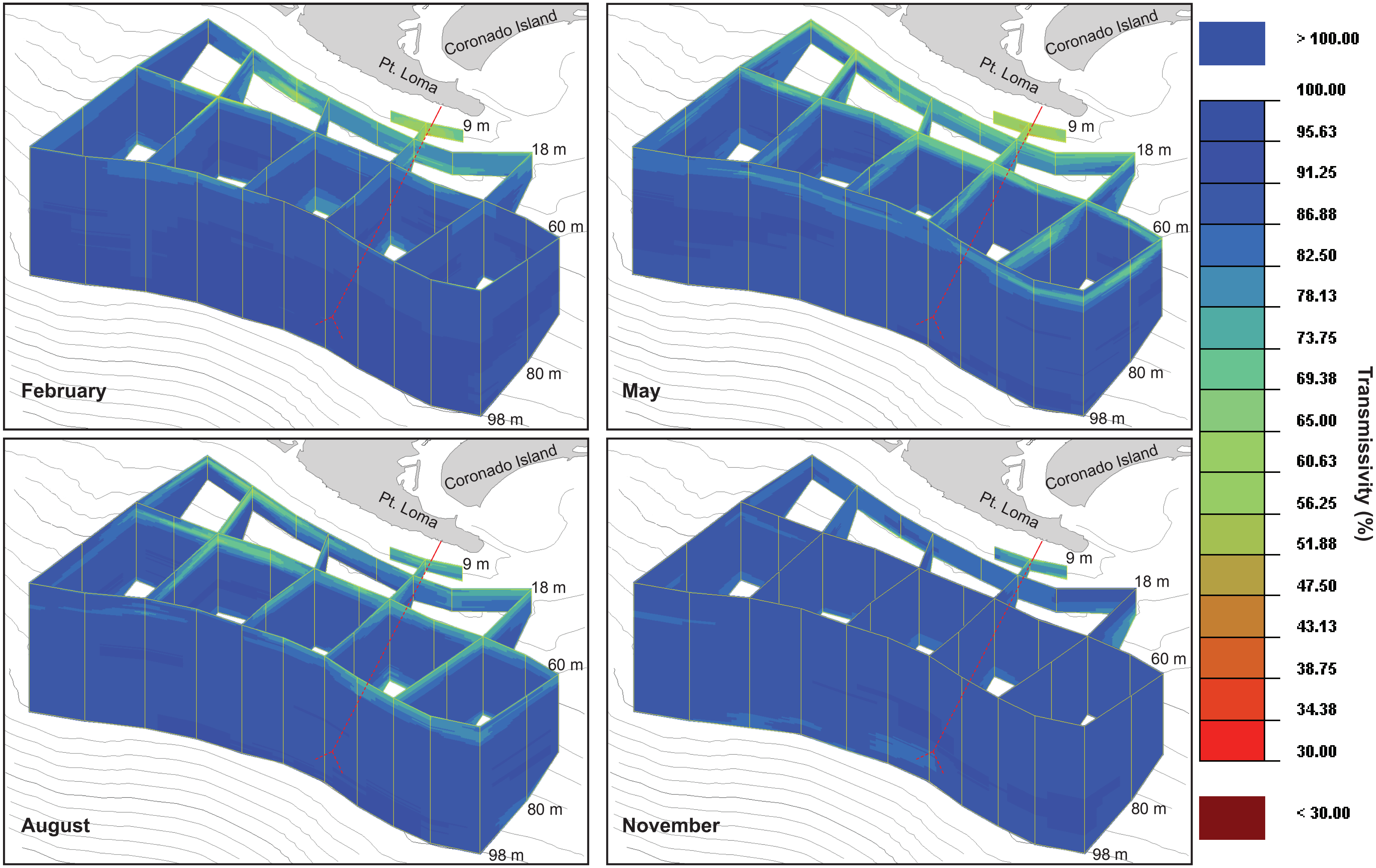
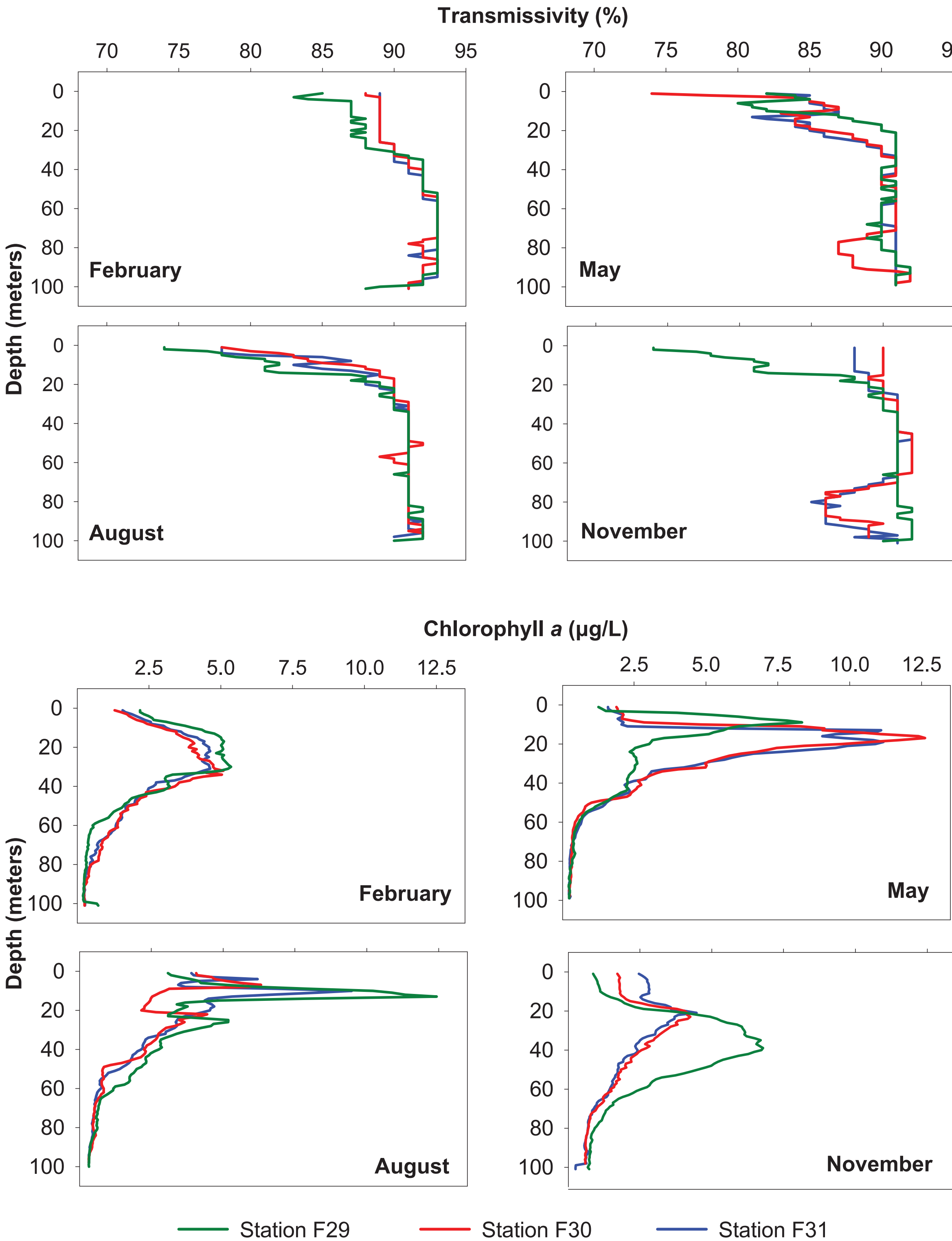


Appendix A.7

Transmissivity recorded in 2009 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.



Appendix A.8

Vertical profiles of transmissivity and chlorophyll *a* for PLOO stations F29, F30, and F31 during 2009.

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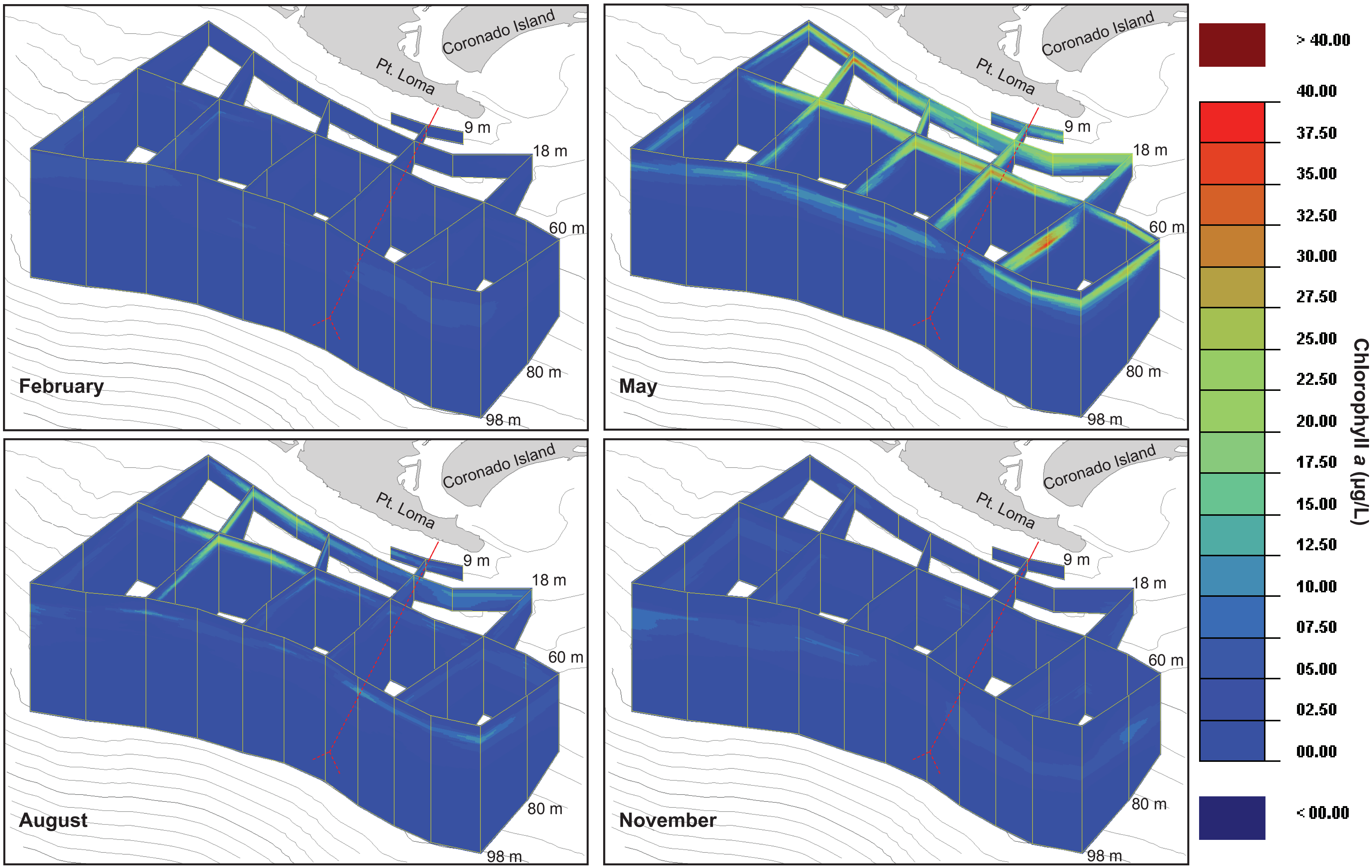

Appendix A.9

Concentrations of chlorophyll *a* recorded in 2009 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

Appendix B

Supporting Data

2009 PLOO Stations

Water Quality

Appendix B.1

Summary of rainfall and bacteria levels at shore stations in the PLOO region during 2009. Rainfall data are from Lindbergh Field, San Diego, CA. Total coliform (Total), fecal coliform (Fecal), and enterococcus (Entero) densities are expressed as mean CFU/100 mL per month and for the entire year. Stations are listed from south to north from left to right.

Month	Rain (in)		D4	D5	D7	D8	D9	D10	D11	D12	All Stations
Jan	0.08	Total	25	68	55	228	25	24	30	9	58
		Fecal	6	10	6	35	10	14	12	3	12
		Entero	6	2	38	56	2	10	6	6	16
Feb	2.63	Total	7	21	9	525	95	57	4031	16	595
		Fecal	2	3	4	131	9	11	103	3	33
		Entero	2	2	4	92	38	10	886	18	131
Mar	0.18	Total	2	11	18	68	17	26	21	24	23
		Fecal	2	2	18	21	2	6	9	12	9
		Entero	3	2	7	11	2	4	6	7	5
Apr	0.14	Total	6	13	9	64	20	24	36	9	23
		Fecal	2	5	2	10	10	5	12	2	6
		Entero	3	2	2	4	2	2	7	2	3
May	0.04	Total	16	96	16	100	14	15	16	6	35
		Fecal	2	10	4	4	2	3	2	3	4
		Entero	4	2	18	3	2	2	2	2	4
Jun	0.03	Total	17	17	52	60	15	17	20	55	32
		Fecal	2	2	6	9	2	6	4	4	4
		Entero	2	2	9	148	2	3	5	2	22
Jul	0.00	Total	11	16	88	24	19	176	37	44	52
		Fecal	3	2	3	3	3	6	10	3	4
		Entero	9	2	4	2	2	3	17	284	41
Aug	Trace	Total	20	20	92	60	24	200	56	13	61
		Fecal	2	2	9	9	2	9	16	6	7
		Entero	2	2	10	11	9	4	10	4	6
Sep	Trace	Total	128	56	56	85	72	24	114	20	70
		Fecal	8	2	10	14	12	8	12	2	8
		Entero	2	2	5	4	4	7	10	2	4
Oct	Trace	Total	56	168	48	3700	56	92	92	57	534
		Fecal	6	6	10	194	6	12	11	8	32
		Entero	48	7	8	1428	10	13	6	12	192
Nov	0.12	Total	17	24	13	325	88	100	32	16	77
		Fecal	2	2	5	42	4	5	4	3	9
		Entero	2	2	2	18	6	5	3	3	5
Dec	2.28	Total	13	79	247	600	497	139	16	306	237
		Fecal	2	5	6	24	6	94	162	6	38
		Entero	2	2	6	2841	28	223	131	13	406
		n	60	60	60	60	60	60	60	60	
Annual Means		**Total**	26	49	59	487	79	74	375	48	
		Fecal	3	4	7	41	6	15	30	5	
		Entero	7	2	10	385	9	24	91	30	

Appendix B.2

Summary of samples with elevated (bold) total coliform (> 1000 CFU/100 mL), fecal coliform (> 400 CFU/100 mL), and/or enterococcus (> 104 CFU/100 mL) densities collected at PLOO shore stations during 2009. Bold F:T values are samples collected in 2009 which meet the FTR criterion for contamination (Total ≥ 1000 CFU/100 mL and F:T ≥ 0.10). Values are expressed as CFU/100 mL; Total = total coliform; Fecal = fecal coliform; Entero = enterococcus; F:T = fecal to total coliform ratio; nd = not detected.

Station	Date	Total	Fecal	Entero	F:T
D7	23 Jan 2009	200	20	**180**	0.10
D8	23 Jan 2009	520	120	**180**	0.23
D11	05 Feb 2009	2	2	**140**	1.00
D8	17 Feb 2009	880	300	**320**	0.34
D11	17 Feb 2009	**>16,000**	400	**3400**	0.03
D8	23 Jun 2009	40	14	**720**	0.35
D12	29 Jul 2009	160	8	**1400**	0.05
D4	03 Oct 2009	20	2	**220**	0.10
D8	03 Oct 2009	300	180	**180**	0.60
D8	09 Oct 2009	800	**600**	**6800**	0.75
D8	27 Oct 2009	**>16,000**	40	26	0.00
D7	09 Dec 2009	**1200**	16	24	0.01
D8	09 Dec 2009	**1800**	20	40	0.01
D9	09 Dec 2009	**2400**	12	58	0.01
D10	09 Dec 2009	nd	180	**340**	—
D11	09 Dec 2009	nd	**800**	**620**	—
D12	09 Dec 2009	**1400**	6	14	0.00
D8	15 Dec 2009	200	28	**140**	0.14
D10	15 Dec 2009	500	280	**320**	0.56
D8	21 Dec 2009	200	40	**14,000**	0.20

Appendix B.3

Summary of samples with elevated (bold) total coliform (> 1000 CFU/100 mL), fecal coliform (> 400 CFU/100 mL), and/or enterococcus (> 104 CFU/100 mL) densities collected at PLOO kelp stations during 2009. Bold F:T values are samples collected in 2009 which meet the FTR criterion for contamination (Total ≥ 1000 CFU/100 mL and F:T ≥ 0.10). Values are expressed as CFU/100 mL; Total = total coliform; Fecal = fecal coliform; Entero = enterococcus; F:T = fecal to total coliform ratio.

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
A1	11 Feb 2009	18	20	2	**120**	0.10
A1	20 May 2009	12	2	2	**460**	1.00
C8	20 May 2009	12	2	2	**160**	1.00
A7	20 May 2009	18	10	2	**440**	0.20
A1	26 May 2009	1	2	2	**180**	1.00
A7	26 May 2009	1	6	2	**110**	0.33
A6	10 Jun 2009	18	2	2	**110**	1.00
A6	22 Jun 2009	1	2	2	**>12,000**	1.00
C7	22 Jun 2009	1	2	2	**>12,000**	1.00
A7	22 Jun 2009	12	12	2	**>12,000**	0.17
A6	28 Jun 2009	1	2	2	**200**	1.00
C8	28 Jun 2009	1	2	2	**140**	1.00
A7	28 Jun 2009	12	2	2	**880**	1.00
C8	08 Aug 2009	1	2	2	**110**	1.00
A6	08 Aug 2009	12	2	2	**140**	1.00
C4	30 Nov 2009	3	20	4	**540**	0.20
C4	04 Dec 2009	3	420	2	**200**	0.00
A1	04 Dec 2009	12	**>16,000**	6	**200**	0.00
A6	04 Dec 2009	12	**8200**	6	**200**	0.00
A7	04 Dec 2009	12	**2800**	2	2	0.00
C8	04 Dec 2009	12	**8400**	2	**200**	0.00
A7	13 Dec 2009	1	**12,000**	2	**200**	0.00
A6	17 Dec 2009	1	**1300**	2	2	0.00
A7	17 Dec 2009	1	**7200**	2	2	0.00
C7	17 Dec 2009	1	**6400**	2	2	0.00

Appendix B.4

Summary of samples with elevated (bold) total coliform (> 1000 CFU/100 mL), fecal coliform (> 400 CFU/100 mL), and/or enterococcus (> 104 CFU/100 mL) densities collected at PLOO offshore stations during 2009. Bold F:T values are samples collected in 2009 which meet the FTR criterion for contamination (Total ≥ 1000 CFU/100 mL and F:T ≥ 0.10). Values are expressed as CFU/100 mL; Total = total coliform; Fecal = fecal coliform; Entero = enterococcus; F:T = fecal to total coliform ratio.

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
F07	10 Feb 2009	60	**2600**	240	32	0.09
F19	10 Feb 2009	80	1000	140	16	**0.14**
F21	10 Feb 2009	80	**1500**	64	30	0.04
F30	10 Feb 2009	80	**2000**	110	22	0.06
F06	12 Feb 2009	60	**1100**	220	32	**0.20**
F15	12 Feb 2009	80	1000	180	14	**0.18**
F16	12 Feb 2009	80	800	**840**	86	1.05
F17	12 Feb 2009	60	**1500**	240	30	**0.16**
F17	12 Feb 2009	80	**5200**	**600**	16	**0.12**
F26	12 Feb 2009	80	**2400**	340	40	**0.14**
F07	05 May 2009	60	**1400**	**480**	72	**0.34**
F08	05 May 2009	60	**4400**	**580**	76	**0.13**
F09	05 May 2009	60	**6000**	**840**	**120**	**0.14**
F10	05 May 2009	60	**1600**	260	32	**0.16**
F19	05 May 2009	60	**>16,000**	**>12,000**	**860**	**0.75**
F19	05 May 2009	80	**8800**	**2000**	**260**	**0.23**
F20	05 May 2009	60	**1600**	220	2	**0.14**
F20	05 May 2009	80	**4200**	**700**	18	**0.17**
F21	05 May 2009	60	**2000**	**860**	86	**0.43**
F21	05 May 2009	80	**5200**	**1000**	**120**	**0.19**
F30	05 May 2009	80	**>16,000**	**>12,000**	**460**	**0.75**
F32	05 May 2009	80	**11,000**	**1000**	**220**	0.09
F06	06 May 2009	25	**6800**	**1800**	86	**0.26**
F29	06 May 2009	60	**2400**	320	16	**0.13**
F29	06 May 2009	80	**>16,000**	**3600**	**300**	**0.23**
F24	03 Aug 2009	80	1000	120	38	**0.12**
F34	03 Aug 2009	60	**1400**	400	44	**0.29**
F34	03 Aug 2009	80	**4600**	**800**	92	**0.17**
F19	05 Aug 2009	80	**3400**	**460**	46	**0.14**
F20	05 Aug 2009	80	**3200**	400	54	**0.13**
F21	05 Aug 2009	60	**3400**	**980**	**260**	**0.29**
F17	06 Aug 2009	80	**2400**	360	38	**0.15**
F18	06 Aug 2009	80	**3200**	**1000**	**140**	**0.31**
F26	06 Aug 2009	80	**12,000**	**1800**	**110**	**0.15**
F27	06 Aug 2009	60	**5600**	**1600**	74	**0.29**
F27	06 Aug 2009	98	**1800**	240	10	**0.13**
F28	06 Aug 2009	60	**2800**	**540**	52	**0.19**
F23	02 Nov 2009	60	**1100**	56	58	0.05
F19	04 Nov 2009	80	1000	160	20	**0.16**
F30	04 Nov 2009	80	**>16,000**	**5000**	**340**	**0.31**
F31	04 Nov 2009	1	**2000**	140	28	0.07
F31	04 Nov 2009	80	**>16,000**	**6000**	**200**	**0.38**
F32	04 Nov 2009	80	1000	**580**	78	**0.58**
F32	04 Nov 2009	98	**2200**	340	64	**0.15**
F33	04 Nov 2009	98	**1200**	220	72	**0.18**

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Appendix B.5

Summary of compliance with California Ocean Plan water contact standards for PLOO shore stations during 2009. The values reflect the number of days that each station exceeded the 30-day total coliform, 10,000 total coliform, 60-day fecal coliform, and 30-day fecal geometric mean standards (see Chapter 3, Box 3.1). Shore stations are listed from south to north from left to right.

Month	# Days	D4	D5	D7	D8	D9	D10	D11	D12
30-Day Total Coliform Standard									
January	31	0	0	0	16	0	0	0	0
February	28	0	0	0	0	0	0	11	0
March	31	0	0	0	0	0	0	18	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	3	0	0	0	0
December	31	0	0	0	0	0	0	0	0
Percent Compliance		**100%**	**100%**	**100%**	**95%**	**100%**	**100%**	**92%**	**100%**
10,000 Total Coliform Standard									
January	31	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	1	0
March	31	0	0	0	0	0	0	0	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0
Total		**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**

Appendix B.5 *continued*

Month	# Days	D4	D5	D7	D8	D9	D10	D11	D12
60-Day Fecal Coliform Standard									
January	31	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	0	0
March	31	0	0	0	0	0	0	0	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	3	0
Percent Compliance		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**99%**	**100%**
30-Day Fecal Geometric Mean Standard									
January	31	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	0	0
March	31	0	0	0	0	0	0	0	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0
Percent Compliance		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix B.6

Summary of compliance with California Ocean Plan water contact standards for PLOO kelp bed stations during 2009. The values reflect the number of days that each station exceeded the 30-day total coliform, 10,000 total coliform, 60-day fecal coliform, and 30-day fecal geometric mean standards (see Chapter 3, Box 3.1). Kelp stations are listed left to right from south to north by depth contour.

		9-m Stations			18-m Stations				
Month	**# Days**	**C4**	**C5**	**C6**	**A1**	**A7**	**A6**	**C7**	**C8**
30-Day Total Coliform Standard									
January	31	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	0	0
March	31	0	0	0	0	0	0	0	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0
Percent Compliance		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
10,000 Total Coliform Standard									
January	31	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	0	0
March	31	0	0	0	0	0	0	0	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0
Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix B.6 *continued*

Month	# Days	9-m Stations			18-m Stations				
		C4	C5	C6	A1	A7	A6	C7	C8
60-Day Fecal Coliform Standard									
January	31	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	0	0
March	31	0	0	0	0	0	0	0	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0
Percent Compliance		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
30-Day Fecal Geometric Mean Standard									
January	31	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	0	0
March	31	0	0	0	0	0	0	0	0
April	30	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0
Percent Compliance		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix C

Supporting Data

2009 PLOO Stations

Sediment Characteristics

Appendix C.1

Constituents and method detection limits (MDL) for sediment samples analyzed for the PLOO monitoring program during 2009.

Parameter	MDL	Parameter	MDL
Organic Indicators			
Total Sulfides (ppm)	0.14	Total Solids (% weight)	0.24
Total Nitrogen (% weight)	0.005	Total Volatile Solids (% weight)	0.11
Total Organic Carbon (% weight)	0.01	Biochemical Oxygen Demand (ppm)	2
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.003
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Tl)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.2
Pesticides (ppt)			
Aldrin	700	Cis Nonachlor	700
Alpha Endosulfan	700	Gamma (trans) Chlordane	700
Beta Endosulfan	700	Heptachlor	700
Dieldrin	700	Heptachlor epoxide	700
Endosulfan Sulfate	700	Methoxychlor	700
Endrin	700	Oxychlordane	700
Endrin aldehyde	700	Trans Nonachlor	700
Hexachlorobenzene (HCB)	400	o,p-DDD	400
Mirex	700	o,p-DDE	700
HCH, Alpha isomer	400	o,p-DDT	700
HCH, Beta isomer	400	p,-p-DDMU	*
HCH, Delta isomer	400	p,p-DDD	700
HCH, Gamma isomer	400	p,p-DDE	400
Alpha (cis) Chlordane	700	p,p-DDT	700

* No MDL available for this parameter.

Appendix C.1 *continued*

Parameter	MDL		Parameter	MDL	
Polychlorinated Biphenyl Congeners (PCBs) (ppt)					
PCB 18	700		PCB 126	1500	
PCB 28	700		PCB 128	700	
PCB 37	700		PCB 138	700	
PCB 44	700		PCB 149	700	
PCB 49	700		PCB 151	700	
PCB 52	700		PCB 153/168	700	
PCB 66	700		PCB 156	700	
PCB 70	700		PCB 157	700	
PCB 74	700		PCB 158	700	
PCB 77	700		PCB 167	700	
PCB 81	700		PCB 169	700	
PCB 87	700		PCB 170	700	
PCB 99	700		PCB 177	700	
PCB 101	700		PCB 180	400	
PCB 105	700		PCB 183	700	
PCB 110	700		PCB 187	700	
PCB 114	700		PCB 189	400	
PCB 118	700		PCB 194	700	
PCB 119	700		PCB 201	700	
PCB 123	700		PCB 206	700	
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
	January	**July**		**January**	**July**
1-methylnaphthalene	40	20	Benzo[K]fluoranthene	70	20
1-methylphenanthrene	40	20	Benzo[e]pyrene	73	20
2,3,5-trimethylnaphthalene	40	20	Biphenyl	40	30
2,6-dimethylnaphthalene	40	20	Chrysene	40	40
2-methylnaphthalene	40	20	Dibenzo(A,H)anthracene	50	20
3,4-benzo(B)fluoranthene	51	20	Fluoranthene	40	20
Acenaphthene	40	20	Fluorene	40	20
Acenaphthylene	40	30	Indeno(1,2,3-CD)pyrene	67	20
Anthracene	40	20	Naphthalene	40	30
Benzo[A]anthracene	40	20	Perylene	40	30
Benzo[A]pyrene	40	20	Phenanthrene	40	30
Benzo[G,H,I]perylene	66	20	Pyrene	40	20

Appendix C.2

Summary of the constituents that make up total chlordane, total DDT, total PCB, and total PAH in each sediment sample collected as part of the PLOO monitoring program during 2009; nd = not detected; ns = not sampled.

Station	Class	Constituent	January	July	Units
B8	DDT	p,p-DDE	ns	700	ppt
B9	DDT	p,p-DDE	550	nd	ppt
B9	PCB	PCB 206	700	nd	ppt
B10	DDT	p,p-DDE	ns	330	ppt
B11	DDT	p,p-DDE	ns	530	ppt
B12	DDT	p,p-DDE	300	nd	ppt
B12	PCB	PCB 206	700	nd	ppt
E1	Chlordane	Alpha (cis) Chlordane	ns	300	ppt
E1	Chlordane	Gamma (trans) Chlordane	ns	650	ppt
E1	DDT	p,p-DDE	ns	740	ppt
E1	DDT	p,p-DDT	ns	380	ppt
E1	PCB	PCB 44	ns	870	ppt
E1	PCB	PCB 49	ns	640	ppt
E1	PCB	PCB 52	ns	1400	ppt
E1	PCB	PCB 66	ns	300	ppt
E1	PCB	PCB 70	ns	900	ppt
E1	PCB	PCB 74	ns	150	ppt
E1	PCB	PCB 87	ns	1300	ppt
E1	PCB	PCB 99	ns	930	ppt
E1	PCB	PCB 101	ns	3000	ppt
E1	PCB	PCB 105	ns	790	ppt
E1	PCB	PCB 110	ns	2500	ppt
E1	PCB	PCB 118	ns	2000	ppt
E1	PCB	PCB 123	ns	190	ppt
E1	PCB	PCB 128	ns	470	ppt
E1	PCB	PCB 149	ns	1500	ppt
E1	PCB	PCB 151	ns	570	ppt
E1	PCB	PCB 153/168	ns	1000	ppt
E1	PCB	PCB 156	ns	190	ppt
E1	PCB	PCB 157	ns	75	ppt
E1	PCB	PCB 158	ns	140	ppt
E1	PCB	PCB 167	ns	110	ppt
E1	PCB	PCB 170	ns	350	ppt
E1	PCB	PCB 177	ns	240	ppt
E1	PCB	PCB 180	ns	2700	ppt

Appendix C.2 *continued*

Station	Class	Constituent	January	July	Units
E2	DDT	p,p-DDE	460	nd	ppt
E2	PAH	3,4-benzo(B)fluoranthene	nd	27	ppb
E2	PAH	Benzo[A]anthracene	nd	22	ppb
E2	PAH	Benzo[A]pyrene	nd	21	ppb
E2	PAH	Chrysene	nd	46	ppb
E2	PCB	PCB 138	nd	280	ppt
E2	PCB	PCB 149	nd	200	ppt
E2	PCB	PCB 153/168	nd	150	ppt
E2	PCB	PCB 180	nd	600	ppt
E2	PCB	PCB 206	700	nd	ppt
E3	Chlordane	Gamma (trans) Chlordane	ns	350	ppt
E3	DDT	p,p-DDD	ns	190	ppt
E3	DDT	p,p-DDE	ns	380	ppt
E3	PAH	3,4-benzo(B)fluoranthene	ns	44	ppb
E3	PAH	Benzo[A]anthracene	ns	35	ppb
E3	PAH	Benzo[A]pyrene	ns	38	ppb
E3	PAH	Benzo[e]pyrene	ns	25	ppb
E3	PAH	Benzo[G,H,I]perylene	ns	27	ppb
E3	PAH	Chrysene	ns	52	ppb
E3	PAH	Fluoranthene	ns	43	ppb
E3	PAH	Pyrene	ns	48	ppb
E3	PCB	PCB 49	ns	270	ppt
E3	PCB	PCB 52	ns	160	ppt
E3	PCB	PCB 66	ns	72	ppt
E3	PCB	PCB 70	ns	220	ppt
E3	PCB	PCB 74	ns	72	ppt
E3	PCB	PCB 87	ns	360	ppt
E3	PCB	PCB 99	ns	230	ppt
E3	PCB	PCB 101	ns	740	ppt
E3	PCB	PCB 105	ns	210	ppt
E3	PCB	PCB 110	ns	640	ppt
E3	PCB	PCB 118	ns	490	ppt
E3	PCB	PCB 119	ns	150	ppt
E3	PCB	PCB 128	ns	170	ppt
E3	PCB	PCB 138	ns	660	ppt
E3	PCB	PCB 149	ns	600	ppt
E3	PCB	PCB 151	ns	220	ppt
E3	PCB	PCB 153/168	ns	370	ppt
E3	PCB	PCB 156	ns	65	ppt
E3	PCB	PCB 158	ns	95	ppt
E3	PCB	PCB 170	ns	140	ppt

Appendix C.2 *continued*

Station	Class	Constituent	January	July	Units
E3	PCB	PCB 177	ns	250	ppt
E3	PCB	PCB 180	ns	660	ppt
E3	PCB	PCB 187	ns	210	ppt
E5	DDT	p,p-DDD	nd	34	ppt
E5	DDT	p,p-DDE	350	410	ppt
E5	DDT	p,p-DDT	nd	140	ppt
E5	PCB	PCB 110	nd	49	ppt
E5	PCB	PCB 149	nd	63	ppt
E5	PCB	PCB 206	700	nd	ppt
E7	DDT	p,p-DDD	ns	70	ppt
E7	DDT	p,p-DDE	ns	590	ppt
E7	PCB	PCB 101	ns	200	ppt
E7	PCB	PCB 110	ns	84	ppt
E7	PCB	PCB 138	ns	160	ppt
E7	PCB	PCB 153/168	ns	68	ppt
E8	DDT	p,p-DDE	330	nd	ppt
E8	PCB	PCB 110	nd	71	ppt
E8	PCB	PCB 206	700	nd	ppt
E9	DDT	o,p-DDE	ns	360	ppt
E9	DDT	p,p-DDE	ns	530	ppt
E9	PAH	3,4-benzo(B)fluoranthene	ns	23	ppb
E9	PAH	Benzo[A]anthracene	ns	26	ppb
E9	PAH	Chrysene	ns	46	ppb
E9	PCB	PCB 28	ns	350	ppt
E9	PCB	PCB 44	ns	270	ppt
E9	PCB	PCB 49	ns	820	ppt
E9	PCB	PCB 52	ns	710	ppt
E9	PCB	PCB 66	ns	630	ppt
E9	PCB	PCB 70	ns	610	ppt
E9	PCB	PCB 74	ns	280	ppt
E9	PCB	PCB 87	ns	630	ppt
E9	PCB	PCB 99	ns	460	ppt
E9	PCB	PCB 101	ns	1500	ppt
E9	PCB	PCB 105	ns	410	ppt
E9	PCB	PCB 110	ns	1200	ppt
E9	PCB	PCB 118	ns	970	ppt
E9	PCB	PCB 128	ns	300	ppt
E9	PCB	PCB 138	ns	940	ppt
E9	PCB	PCB 149	ns	630	ppt

Appendix C.2 *continued*

Station	Class	Constituent	January	July	Units
E9	PCB	PCB 151	ns	290	ppt
E9	PCB	PCB 153/168	ns	350	ppt
E9	PCB	PCB 156	ns	130	ppt
E9	PCB	PCB 158	ns	110	ppt
E9	PCB	PCB 167	ns	53	ppt
E9	PCB	PCB 170	ns	78	ppt
E9	PCB	PCB 187	ns	89	ppt
E11	DDT	p,p-DDE	280	320	ppt
E11	DDT	p,p-DDT	660	nd	ppt
E11	PCB	PCB 44	700	nd	ppt
E11	PCB	PCB 52	930	nd	ppt
E11	PCB	PCB 87	700	nd	ppt
E11	PCB	PCB 99	700	nd	ppt
E11	PCB	PCB 101	720	nd	ppt
E11	PCB	PCB 105	700	nd	ppt
E11	PCB	PCB 110	790	nd	ppt
E11	PCB	PCB 118	700	nd	ppt
E11	PCB	PCB 128	700	nd	ppt
E11	PCB	PCB 149	700	nd	ppt
E11	PCB	PCB 151	700	nd	ppt
E11	PCB	PCB 153/168	700	nd	ppt
E11	PCB	PCB 206	700	nd	ppt
E14	DDT	p,p-DDE	230	nd	ppt
E14	PCB	PCB 206	700	nd	ppt
E17	DDT	p,p-DDE	400	nd	ppt
E17	PCB	PCB 206	700	nd	ppt
E19	DDT	p,p-DDE	ns	460	ppt
E20	DDT	p,p-DDE	350	490	ppt
E20	DDT	p,p-DDT	nd	440	ppt
E20	PCB	PCB 206	700	nd	ppt
E21	DDT	p,p-DDT	ns	150	ppt
E23	DDT	p,p-DDE	280	nd	ppt
E25	DDT	p,p-DDE	400	nd	ppt
E25	PCB	PCB 206	700	nd	ppt
E26	DDT	p,p-DDE	nd	340	ppt

Appendix C.3

PLOO sediment statistics for the January 2009 survey. SD = standard deviation; ns = not sampled. Pre-discharge period = 1991–1993.

	Depth (m)	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skewness (phi)	Kurtosis (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
North Reference Stations													
B8	88	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
B11	88	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
B9	98	0.051	4.3	1.6	3.8	0.5	0.9	0.0	56.3	40.6	3.1	43.7	Silt with fine sand, shell hash, some pea gravel
B12	98	0.067	3.9	1.8	3.2	0.5	1.0	2.0	64.6	30.5	2.9	33.4	Sand with fine and coarse sand, shell hash
B10	116	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stations North of the Outfall													
E19	88	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E20	98	0.060	4.1	1.4	3.6	0.5	1.2	0.0	62.1	36.0	1.8	37.9	Silt with fine sand, shell hash, some organics
E23	98	0.056	4.2	1.4	3.7	0.4	1.2	0.0	59.0	38.6	2.4	41.0	Silt with fine sand, shell hash, some organics
E25	98	0.055	4.2	1.5	3.7	0.5	1.1	0.0	59.2	38.1	2.8	40.8	Silt with fine sand, shell hash, some organics
E26	98	0.050	4.3	1.6	3.8	0.4	1.0	0.0	55.2	41.9	2.9	44.8	Silt with fine sand and shell hash
E21	116	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nearfield Stations													
E11	98	0.065	3.9	1.4	3.6	0.4	1.2	0.0	66.2	31.7	2.1	33.8	Silt with fine sand, shell hash, some organics
E14	98	0.071	3.8	1.5	3.5	0.4	1.3	4.0	66.3	27.7	1.9	29.6	Silt with fine sand and shell hash, gravel
E17	98	0.066	3.9	1.3	3.6	0.4	1.2	0.0	67.7	30.5	1.8	32.2	Silt with fine sand, some shell hash, organics
E15	116	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stations South of the Outfall													
E1	88	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E7	88	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E2	98	0.056	4.2	1.7	3.7	0.4	0.9	2.3	55.2	39.6	2.8	42.5	Sand with fine and coarse sand, shell hash
E5	98	0.062	4.0	1.5	3.5	0.5	1.1	0.0	64.0	33.8	2.2	36.0	Silt and clay with some shell hash, organics
E8	98	0.065	3.9	1.4	3.5	0.5	1.2	0.0	65.3	32.6	2.1	34.7	Clay and silt with some shell hash
E3	116	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E9	116	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
January Max		0.071	4.3	1.8	3.8	0.5	1.3	4.0	67.7	41.9	3.1	44.8	
Pre-discharge Max*		0.117	5.6	2.6	5.5	1.9	3.9	6.9	79.0	60.5	13.7	74.2	

* Based on primary core stations only.

Appendix C.3 *continued*

PLOO sediment statistics for the July 2009 survey. Cbs = coarse black sand; SD = standard deviation. Pre-discharge period = 1991–1993.

	Depth (m)	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skewness (phi)	Kurtosis (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
North Reference Stations													
B8	88	0.042	4.6	1.5	4.3	0.3	1.0	0.0	43.2	53.8	3.0	56.8	Silt and clay, some shell hash, organics
B11	88	0.049	4.4	1.8	3.9	0.4	0.8	1.4	50.3	43.8	4.5	48.3	Silt with fine and coarse sand, shell hash, gravel
B9	98	0.054	4.2	1.6	3.7	0.5	1.0	0.0	58.8	38.4	2.8	41.2	Silt with fine sand, pea gravel, shell hash
B12	98	0.069	3.9	1.7	3.2	0.6	1.1	0.0	68.6	28.5	2.8	31.4	Silt with fine and coarse sand, shell hash, gravel
B10	116	0.071	3.8	1.4	3.2	0.7	1.4	0.0	72.1	25.7	2.2	27.9	Silt with fine sand, shell hash
Stations North of the Outfall													
E19	88	0.053	4.2	1.4	3.8	0.4	1.2	0.0	55.9	41.6	2.5	44.1	Silt with fine sand, shell hash, organic material
E20	98	0.059	4.1	1.4	3.7	0.4	1.2	0.0	63.1	34.5	2.4	36.9	Silt with fine sand, shell hash, organic material
E23	98	0.055	4.2	1.5	3.8	0.4	1.1	0.0	59.4	38.0	2.6	40.6	Silt with fine sand, shell hash
E25	98	0.058	4.1	1.5	3.7	0.5	1.2	0.0	60.7	36.7	2.6	39.3	Silt with clay, shell hash, organic material
E26	98	0.054	4.2	1.5	3.8	0.5	1.1	0.0	58.0	39.2	2.8	42.0	Silt with clay, shell hash
E21	116	0.065	4.0	1.4	3.5	0.5	1.3	0.0	67.2	30.7	2.2	32.8	Silt with fine sand, shell hash, organic material
Nearfield Stations													
E11	98	0.069	3.9	1.4	3.4	0.5	1.3	0.0	68.4	29.6	2.0	31.6	Silt and shell hash
E14	98	0.061	4.0	0.7	4.0	0.0	40.0	8.0	62.3	29.7	0.0	29.7	Silt with cbs, shell hash, rocks
E17	98	0.066	3.9	1.4	3.5	0.5	1.3	0.0	66.8	31.2	2.0	33.2	Silt with fine sand, shell hash, organic material
E15	116	0.064	4.0	1.4	3.5	0.5	1.2	0.0	68.7	29.1	2.2	31.3	Silt, clay, fine sand, cbs, shell hash, organics
Stations South of the Outfall													
E1	88	0.055	4.2	1.7	3.7	0.4	0.9	0.0	55.9	40.8	3.3	44.1	Silt with clay, shell hash, coarse sand, gravel, rocks
E7	88	0.052	4.3	1.5	3.8	0.4	1.1	0.0	56.0	40.8	3.2	44.0	Clay and silt, shell hash, organic material
E2	98	0.120	3.1	1.8	3.5	-0.5	1.1	9.3	55.4	35.3	0.0	35.3	Silt with clay, coarse sand, gravel rocks, shell hash
E5	98	0.059	4.1	1.5	3.6	0.5	1.1	0.0	62.4	35.4	2.2	37.6	Silt with coarse sand and shell hash
E8	98	0.064	4.0	1.4	3.5	0.5	1.2	0.0	64.6	33.3	2.1	35.4	Silt with cbs and shell hash
E3	116	0.068	3.9	1.9	3.1	0.6	0.8	0.0	63.9	33.1	3.0	36.1	Silt, clay, fine and coarse sand, shell hash, rocks
E9	116	0.052	4.3	1.7	3.7	0.5	0.9	0.0	58.2	38.7	3.1	41.8	Silt, fine sand, cbs, shell hash, gravel
July Max		0.120	4.6	1.9	4.3	0.7	40.0	9.3	72.1	53.8	4.5	56.8	
Pre-discharge Max		0.125	5.8	3.0	5.6	1.9	8.1	26.4	79.0	62.0	13.9	74.2	

Appendix C.4

Summary of organic loading indicators at PLOO benthic stations for the January and July 2009 surveys. BOD = biochemical oxygen demand; TN = total nitrogen; TOC = total organic carbon; TVS = total volatile solids; DR = detection rate; % wt = percent weight; nd = not detected; ns = not sampled.

	January					July					
	BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)		BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
North Reference Stations						*North Reference Stations*					
B8	ns	ns	ns	ns	ns	B8	300	0.86	0.087	0.968	3.28
B11	ns	ns	ns	ns	ns	B11	445	0.23	0.083	3.220	4.24
B9	357	*	0.060	0.984	5.42	B9	491	0.52	0.056	0.945	2.79
B12	354	*	0.054	4.270	3.35	B12	350	0.24	0.054	3.720	2.90
B10	ns	ns	ns	ns	ns	B10	348	nd	0.054	1.680	2.58
Stations North of the Outfall						*Stations North of the Outfall*					
E19	ns	ns	ns	ns	ns	E19	194	0.87	0.053	0.636	2.26
E20	193	1.43	0.053	0.604	1.87	E20	245	0.79	0.053	0.629	2.17
E23	257	1.54	0.055	0.653	2.18	E23	188	1.15	0.055	0.662	2.32
E25	252	1.32	0.057	0.733	2.18	E25	>535	1.95	0.051	0.695	2.47
E26	407	3.09	0.067	0.789	2.41	E26	287	3.49	0.063	0.784	2.46
E21	ns	ns	ns	ns	ns	E21	215	0.63	0.044	0.596	2.14
Nearfield Stations						*Nearfield Stations*					
E11	301	0.61	0.043	0.692	2.68	E11	182	2.64	0.036	0.767	2.11
E14	227	13.80	0.042	0.626	1.67	E14	266	33.90	0.044	0.619	2.14
E17	270	1.38	0.043	0.523	1.68	E17	269	6.25	0.042	0.516	1.97
E15	ns	ns	ns	ns	ns	E15	196	5.76	0.045	0.813	2.20
Stations South of the Outfall						*Stations South of the Outfall*					
E1	ns	ns	ns	ns	ns	E1	211	2.12	0.044	0.505	2.05
E7	ns	ns	ns	ns	ns	E7	195	1.19	0.048	0.605	2.30
E2	179	3.67	0.049	0.693	2.24	E2	201	0.51	0.047	0.758	2.44
E5	230	0.29	0.052	0.819	2.15	E5	170	1.57	0.034	0.611	2.27
E8	nd	1.98	0.040	0.721	1.89	E8	167	1.00	0.034	0.610	2.19
E3	ns	ns	ns	ns	ns	E3	222	8.10	0.030	0.463	1.70
E9	ns	ns	ns	ns	ns	E9	195	0.91	0.051	1.780	2.67
DR (%)	92	100	100	100	100	DR (%)	100	95	100	100	100

* Sample held over time limit; results not reportable.

Appendix C.5

Concentrations of trace metals (ppm) for the January 2009 PLOO survey. ERL = effects range low threshold value; ERM = effects range median threshold value; na = not available; nd = not detected; ns = not sampled. See Appendix C.1 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
North Reference Stations																		
B8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
B11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
B9	7540	0.4	3.76	58.8	nd	0.12	19.2	6.3	14,400	4.3	90.3	0.025	7.3	nd	nd	nd	0.7	33.9
B12	3130	nd	7.27	10.3	nd	0.09	13.3	1.5	11,800	2.4	35.9	0.015	3.3	nd	nd	nd	nd	20.0
B10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stations North of the Outfall																		
E19	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E20	7040	0.3	2.50	33.8	nd	0.14	15.1	6.1	10,300	4.0	80.8	0.028	6.6	nd	nd	nd	0.4	26.7
E23	8090	nd	3.24	36.4	nd	0.13	16.0	6.3	11,300	4.0	86.4	0.028	7.2	nd	nd	nd	0.3	28.6
E25	7560	nd	2.79	33.5	nd	0.10	15.5	6.5	11,000	4.2	84.9	0.024	6.8	nd	nd	nd	0.7	28.8
E26	9700	0.3	2.88	38.5	nd	0.15	17.8	7.2	12,300	4.2	101.0	0.026	8.1	nd	nd	nd	0.7	32.2
E21	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nearfield Stations																		
E11	6350	nd	2.72	29.0	nd	0.12	13.3	5.3	9760	3.1	73.0	0.019	5.8	nd	nd	nd	0.6	24.5
E14	6110	0.3	3.71	33.8	nd	0.17	14.3	6.9	10,200	13.2	75.5	0.020	6.5	nd	nd	nd	0.7	25.8
E17	6590	nd	3.81	28.9	nd	0.13	13.9	5.3	9790	3.6	71.8	0.020	6.0	nd	nd	nd	nd	24.8
E15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stations South of the Outfall																		
E1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E7	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E2	4020	nd	3.26	27.6	nd	nd	8.6	5.4	7170	2.9	49.9	0.040	3.5	0.24	nd	nd	nd	19.8
E5	3340	nd	2.56	17.4	nd	nd	7.4	3.9	5570	2.1	40.3	0.023	3.1	nd	nd	nd	0.3	14.3
E8	6740	nd	2.47	28.3	nd	0.09	13.7	5.1	9870	3.4	72.1	0.019	5.7	nd	nd	nd	0.5	25.1
E3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Detection Rate (%)	100	33	100	100	0	83	100	100	100	100	100	100	100	8	0	0	75	100
ERL	na	na	8.2	na	na	1.20	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

Appendix C.5 *continued*

Concentrations of trace metals (ppm) for the July 2009 PLOO survey. ERL = effects range low threshold value; ERM = effects range median threshold value; na = not available; nd = not detected. See Appendix C.1 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
North Reference Stations																		
B8	8300	nd	4.12	50.0	0.26	0.15	19.6	9.0	13,000	6.7	112.0	0.033	9.1	nd	nd	nd	1.2	38.0
B11	8610	nd	4.25	39.8	0.31	0.17	21.3	8.3	16,300	5.9	114.0	0.040	8.6	nd	nd	nd	1.1	39.7
B9	7090	nd	3.29	58.4	0.28	0.14	20.6	5.8	14,500	5.3	91.1	0.022	7.5	nd	nd	nd	0.9	36.3
B12	5000	nd	5.68	19.8	0.34	0.18	23.6	3.1	17,900	4.1	55.7	0.014	5.6	nd	nd	nd	0.6	34.2
B10	5060	nd	2.44	24.7	0.23	0.15	17.3	5.0	10,800	3.9	61.2	0.015	5.5	nd	nd	nd	0.7	29.6
Stations North of the Outfall																		
E19	9190	nd	2.42	40.3	0.22	0.12	16.6	6.5	12,800	3.7	99.6	0.022	7.9	nd	nd	nd	1.0	30.6
E20	9910	nd	2.44	37.0	0.23	0.14	16.7	6.5	12,600	3.9	103.0	0.024	7.8	nd	nd	nd	1.0	30.1
E23	9760	nd	2.76	37.3	0.22	0.12	16.8	7.0	12,800	4.0	99.9	0.018	8.8	nd	nd	nd	1.0	30.4
E25	7200	nd	1.49	35.5	0.20	0.17	15.1	7.4	10,100	4.2	82.3	0.021	7.2	nd	nd	nd	0.8	28.2
E26	7760	nd	2.91	38.7	0.22	0.16	16.2	7.6	10,800	4.5	87.1	0.040	7.9	nd	nd	nd	0.9	29.9
E21	7560	nd	2.77	29.1	0.19	0.13	14.8	5.9	11,100	3.8	77.4	0.014	6.9	0.25	nd	nd	0.9	25.9
Nearfield Stations																		
E11	7850	nd	2.38	27.4	0.19	0.12	14.5	6.0	10,800	3.0	80.1	0.030	6.5	nd	nd	nd	0.9	25.3
E14	7810	nd	2.66	31.6	0.19	0.15	14.0	6.1	10,500	2.9	85.2	0.009	6.4	nd	nd	nd	0.9	25.9
E17	6370	nd	2.28	27.6	0.17	0.14	13.5	5.3	9990	3.4	71.1	0.010	6.7	nd	nd	nd	0.9	24.7
E15	6750	nd	2.44	25.6	0.18	0.10	14.1	5.3	10,300	3.5	71.1	0.026	6.4	nd	nd	nd	0.8	24.3
Stations South of the Outfall																		
E1	11,300	nd	3.25	54.1	0.25	0.09	17.8	9.4	15,000	6.3	108.0	0.058	8.6	nd	nd	nd	1.3	36.4
E7	8700	nd	3.50	40.7	0.22	0.11	16.4	7.2	12,700	4.6	94.1	0.035	7.7	nd	nd	nd	1.0	30.0
E2	9410	nd	3.62	58.7	0.25	0.12	18.6	11.4	16,300	6.3	109.0	0.063	8.3	nd	nd	nd	1.3	37.7
E5	8820	nd	2.51	34.7	0.20	0.08	14.6	5.9	11,800	3.3	87.3	0.043	6.6	nd	nd	nd	0.9	27.1
E8	8470	nd	2.48	30.4	0.20	0.10	14.5	5.7	11,300	3.3	86.9	0.028	6.5	nd	nd	nd	0.9	26.4
E3	8290	nd	2.22	48.9	0.19	0.10	15.9	10.7	13,300	8.6	105.0	0.065	5.3	nd	nd	nd	1.0	36.4
E9	9720	nd	3.76	33.7	0.27	0.17	20.0	11.7	15,400	5.5	90.6	0.032	7.7	nd	nd	nd	1.2	47.8
Detection Rate (%)	100	0	100	100	100	100	100	100	100	100	100	100	100	5	0	0	100	100
ERL	na	na	8.2	na	na	1.20	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

Appendix C.6

Concentrations of chlordane, endrin aldehyde (EA), total DDT (tDDT), total PCB (tPCB), and total PAH (tPAH) detected at each PLOO benthic station during the January and July 2009 surveys. DR = detection rate; ERL = effects range low threshold value; ERM = effects range median threshold value; na = not available; nd = not detected; ns = not sampled.

	January						July						
	Chlordane (ppt)	EA (ppt)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)	tPAH (ppb)		Chlordane (ppt)	EA (ppt)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)	tPAH (ppb)
North Reference Stations							*North Reference Stations*						
B8	ns	ns	ns	ns	ns	ns	B8	nd	nd	700	nd	nd	nd
B11	ns	ns	ns	ns	ns	ns	B11	nd	nd	530	nd	nd	nd
B9	nd	nd	550	96	560	nd	B9	nd	nd	nd	nd	nd	nd
B12	nd	nd	300	67	320	nd	B12	nd	nd	nd	nd	nd	nd
B10	ns	ns	ns	ns	ns	ns	B10	nd	nd	330	79	nd	nd
Stations North of the Outfall							*Stations North of the Outfall*						
E19	ns	ns	ns	ns	ns	ns	E19	nd	nd	460	88	nd	nd
E20	nd	nd	350	nd	380	nd	E20	nd	nd	930	nd	nd	nd
E23	nd	nd	280	nd	nd	nd	E23	nd	nd	nd	nd	nd	nd
E25	nd	nd	400	nd	570	nd	E25	nd	nd	nd	nd	nd	nd
E26	nd	nd	nd	nd	nd	nd	E26	nd	nd	340	150	nd	nd
E21	ns	ns	ns	ns	ns	ns	E21	nd	nd	150	nd	nd	nd
Nearfield Stations							*Nearfield Stations*						
E11	nd	nd	940	nd	5400	nd	E11	nd	nd	320	470	nd	nd
E14	nd	nd	230	nd	400	nd	E14	nd	nd	nd	nd	nd	nd
E17	nd	nd	400	nd	620	nd	E17	nd	nd	nd	nd	nd	nd
E15	ns	ns	ns	ns	ns	ns	E15	nd	nd	nd	nd	nd	nd
Stations South of the Outfall							*Stations South of the Outfall*						
E1	ns	ns	ns	ns	ns	ns	E1	950	nd	1120	750	22,315	nd
E7	ns	ns	ns	ns	ns	ns	E7	nd	nd	660	310	512	nd
E2	nd	nd	460	nd	630	nd	E2	nd	nd	nd	1600	1230	116
E5	nd	nd	350	nd	530	nd	E5	nd	nd	584	270	112	nd
E8	nd	nd	330	nd	620	nd	E8	nd	970	nd	nd	71	nd
E3	ns	ns	ns	ns	ns	ns	E3	350	nd	570	nd	7054	312
E9	ns	ns	ns	ns	ns	ns	E9	nd	nd	890	270	11,810	95
DR (%)	0	0	92	17	83	0	DR (%)	9	5	59	41	32	14
ERL	na	na	1580	na	na	4022	ERL	na	na	1580	na	na	4022
ERM	na	na	46,100	na	na	44,792	ERM	na	na	46,100	na	na	44,792

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Appendix D

Supporting Data

2009 PLOO Stations

Macrobenthic Communities

Appendix D.1

All taxa composing cluster groups A–G from the 2009 surveys of PLOO benthic stations. Data are expressed as mean abundance per sample (no./0.1 m^2) for each group. Number of station/survey entities per cluster group shown in parentheses.

		Cluster Group						
Species/Taxa	Phyla	A (2)	B (1)	C (3)	D (1)	E (3)	F (1)	G (23)
Acanthoptilum sp	Cnidaria					0.2		0.8
Acila castrensis	Mollusca							<0.1
Acoetes pacifica	Annelida							0.1
Acteocina cerealis	Mollusca	0.3	5.5	0.2	1.5	0.5	0.5	1.3
Acteon traskii	Mollusca			0.3				
Actiniaria	Cnidaria			0.2		0.2		
Adontorhina cyclia	Mollusca	1.3	1.0	5.8	35.0	0.2	6.0	5.7
Aglaja ocelligera	Mollusca		0.5	0.3				
Aglaophamus verrilli	Annelida	0.3		1.0	0.5	0.7		0.3
Agnezia septentrionalis	Chordata			0.5				
Alvania rosana	Mollusca	0.3	3.5	0.2		0.2	0.5	0.6
Amaeana occidentalis	Annelida	0.3	1.5	1.0		0.5	0.5	0.2
Amage anops	Annelida			0.3	0.5			0.2
Americhelidium shoemakeri	Arthropoda						0.5	0.1
Americhelidium sp SD4	Arthropoda		0.5					0.1
Ampelisca agassizi	Arthropoda					0.3		<0.1
Ampelisca brevisimulata	Arthropoda			1.7	2.0	0.5	0.5	1.1
Ampelisca careyi	Arthropoda	5.8	0.5	3.8	0.5	1.8	5.0	2.5
Ampelisca cf *brevisimulata*	Arthropoda	0.5	1.5	0.2	0.5	0.7		0.4
Ampelisca cristata cristata	Arthropoda							0.2
Ampelisca cristata microdentata	Arthropoda							0.1
Ampelisca hancocki	Arthropoda	0.8	0.5	1.5	1.0	0.5		1.7
Ampelisca indentata	Arthropoda			0.7		0.2		<0.1
Ampelisca pacifica	Arthropoda	2.0	2.0	4.2	5.5	3.7	2.0	4.2
Ampelisca pugetica	Arthropoda	2.8	0.5	3.8	0.5	1.5	3.5	1.4
Ampelisca romigi	Arthropoda			1.7			1.5	<0.1
Ampelisca sp	Arthropoda			0.2	0.5	0.2		0.4
Ampharete finmarchica	Annelida	0.3	0.5	1.3		0.2		0.4
Ampharete labrops	Annelida			0.2				<0.1
Ampharete sp	Annelida	0.3				0.2		<0.1
Ampharetidae sp SD1	Annelida		0.5	0.2		0.3		0.2
Ampharetidae	Annelida	0.3		0.2				
Amphichondrius granulatus	Echinodermata			1.3		0.5		0.3
Amphicteis mucronata	Annelida	0.3						<0.1
Amphicteis scaphobranchiata	Annelida	1.0	1.0	1.5	0.5	0.7		0.9
Amphicteis sp	Annelida							<0.1
Amphiodia digitata	Echinodermata	10.0		7.8		0.5	4.0	0.3
Amphiodia sp	Echinodermata	3.3		5.3	1.0	5.2	2.0	3.4

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Amphiodia urtica	Echinodermata	1.5		14.5	71.5	71.0	2.5	25.0
Amphioplus sp	Echinodermata	0.5						
Amphipholis squamata	Echinodermata		1.5	0.2				
Amphissa bicolor	Mollusca							0.1
Amphissa undata	Mollusca	1.0	1.0	0.2				<0.1
Amphiura arcystata	Echinodermata			0.3	1.0	1.2		0.2
Amphiuridae	Echinodermata	1.8		2.8	2.0	1.2	1.0	0.5
Amygdalum politum	Mollusca							<0.1
Anarthron sp SD1	Arthropoda	0.3						
Anarthruridae	Arthropoda			0.2				<0.1
Anemonactis sp	Cnidaria			0.2				
Anobothrus gracilis	Annelida	0.3		0.8	0.5	0.3	1.0	0.7
Anonyx lilljeborgi	Arthropoda	0.8			0.5	0.3		0.2
Aoroides sp A	Arthropoda		9.0					
Aoroides sp	Arthropoda			0.2				
Aphelochaeta glandaria complex	Annelida	13.8	13.0	2.7	0.5	0.3	9.0	6.9
Aphelochaeta monilaris	Annelida	1.0	1.5	0.2	0.5	3.5	11.5	2.8
Aphelochaeta petersenae	Annelida						0.5	
Aphelochaeta phillipsi	Annelida			0.2			0.5	
Aphelochaeta sp LA1	Annelida	0.8		0.8		0.8	1.0	0.3
Aphelochaeta sp SD13	Annelida	4.3	1.0	12.3			4.0	1.2
Aphelochaeta sp	Annelida					0.8		0.2
Aphelochaeta tigrina	Annelida	1.5		1.0		0.2	2.0	0.2
Aphelochaeta williamsae	Annelida						1.0	<0.1
Aphrodita sp	Annelida	0.3						
Arachnanthus sp A	Cnidaria					0.3		
Araphura breviaria	Arthropoda	0.3		0.3			0.5	0.8
Araphura cuspirostris	Arthropoda			0.2				0.1
Araphura sp SD1	Arthropoda							0.5
Argissa hamatipes	Arthropoda			0.2		0.2		<0.1
Aricidea (*Acmira*) *catherinae*	Annelida	13.0	18.0	20.3		2.3	1.0	10.7
Aricidea (*Acmira*) *lopezi*	Annelida	4.3		0.8		2.5	5.5	5.0
Aricidea (*Acmira*) *rubra*	Annelida			0.3				<0.1
Aricidea (*Acmira*) *simplex*	Annelida	1.3	3.0	1.3	0.5	3.3	0.5	1.9
Aricidea (*Acmira*) sp	Annelida							<0.1
Aricidea (*Allia*) *antennata*	Annelida	1.0		0.3		0.2	0.5	0.7
Aricidea (*Allia*) *hartleyi*	Annelida			0.5				0.2
Aricidea (*Allia*) sp A	Annelida							<0.1
Aricidea (*Allia*) sp	Annelida	0.8	1.0	3.7	1.0	1.0		3.8
Aricidea (*Aricidea*) *wassi*	Annelida	0.8				0.2		0.3
Artacama coniferi	Annelida			0.3		0.3		0.1
Artacamella hancocki	Annelida	0.3		2.0		0.7	1.0	0.2

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Aruga holmesi	Arthropoda			0.2				
Aruga oculata	Arthropoda		0.5	0.2		0.3		0.2
Asabellides lineata	Annelida	0.3		0.5				<0.1
Ascidiacea	Chordata			0.5				<0.1
Asteroidea	Echinodermata	0.3		0.2	0.5			<0.1
Astropecten sp	Echinodermata							<0.1
Axinopsida serricata	Mollusca	2.5	4.5	8.5	35.0	1.3	34.5	18.9
Balanoglossus sp	Chordata			0.2		0.2		0.1
Bathymedon pumilus	Arthropoda			0.3		0.3		0.4
Bivalvia	Mollusca					0.2		<0.1
Brada pluribranchiata	Annelida				1.0			<0.1
Brada villosa	Annelida				0.5			<0.1
Bullomorpha sp A	Mollusca				0.5			
Byblis millsi	Arthropoda	0.5		0.8	1.0	0.2		0.4
Byblis sp	Arthropoda							<0.1
Byblis veleronis	Arthropoda			0.2				<0.1
Caecognathia crenulatifrons	Arthropoda	3.3	3.0	2.8		1.8	1.0	2.5
Campylaspis canaliculata	Arthropoda							0.2
Campylaspis rubromaculata	Arthropoda			0.3				0.1
Capitella teleta	Annelida		62.0					1.8
Capitellidae	Annelida							<0.1
Caprella mendax	Arthropoda			0.2		0.7		
Cardiomya pectinata	Mollusca					0.2		
Cardiomya planetica	Mollusca							<0.1
Caridea	Arthropoda							<0.1
Carinoma mutabilis	Nemertea			0.2				0.1
Cephalophoxoides homilis	Arthropoda			0.2				0.1
Cerebratulus californiensis	Nemertea	0.3					0.5	<0.1
Chaetoderma marinelli	Mollusca			0.2				<0.1
Chaetoderma pacificum	Mollusca			0.2				
Chaetozone hartmanae	Annelida	1.8	7.0	4.5	1.0	5.3	9.0	8.3
Chaetozone sp SD1	Annelida	3.8		1.2		0.8	4.5	0.4
Chaetozone sp SD2	Annelida	1.5						<0.1
Chaetozone sp SD3	Annelida	1.0						<0.1
Chaetozone sp SD4	Annelida	1.3						<0.1
Chaetozone sp SD5	Annelida	2.5						
Chaetozone sp	Annelida	2.8		0.2			0.5	0.1
Chaetozone spinosa	Annelida			0.7				<0.1
Chauliopleona dentata	Arthropoda	1.0		0.3		0.7	0.5	0.6
Chiridota sp	Echinodermata		0.5	0.2	1.0	0.5	0.5	0.4
Chloeia pinnata	Annelida	3.0	8.0	0.2				0.6
Chone albocincta	Annelida							0.2

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Chone paramollis	Annelida							0.1
Chone sp B	Annelida			0.2				0.1
Chone sp	Annelida			0.2				
Chone trilineata	Annelida	2.5	3.0	4.7		1.5	2.5	1.0
Cirratulidae	Annelida		0.5					0.3
Cirratulus sp	Annelida							0.1
Cirrophorus furcatus	Annelida			0.2				
Clymenura gracilis	Annelida	0.3	0.5	1.2	4.5	2.7	0.5	2.2
Compressidens stearnsii	Mollusca	0.5	0.5	1.8	1.5	0.7	0.5	0.4
Compsomyax subdiaphana	Mollusca							<0.1
Corophiida	Arthropoda							<0.1
Cossura candida	Annelida			1.7		0.3		0.4
Cossura sp A	Annelida			1.2		0.7		0.2
Cossura sp	Annelida	0.3				0.2		<0.1
Cumanotus fernaldi	Mollusca		2.0					
Cuspidaria parapodema	Mollusca				0.5	0.2		0.1
Cyclocardia ventricosa	Mollusca	0.5						
Cyclopecten catalinensis	Mollusca							<0.1
Cylichna diegensis	Mollusca		1.0	0.3	0.5	1.0	0.5	0.4
Cylindroleberididae	Arthropoda			0.2				<0.1
Dactylopleustes sp A	Arthropoda							<0.1
Decamastus gracilis	Annelida	5.0	8.0	5.3	0.5	0.2	6.0	2.9
Deflexilodes norvegicus	Arthropoda	0.5	1.5	0.3	0.5	0.8	1.0	1.0
Deilocerus decorus	Arthropoda			0.3				
Dentalium vallicolens	Mollusca			0.2				
Desdimelita desdichada	Arthropoda		0.5					
Diaphorodoris lirulatocauda	Mollusca		0.5					
Diastylidae	Arthropoda							<0.1
Diastylis crenellata	Arthropoda	0.8	2.5	1.3	1.5	0.7	2.0	1.3
Dipolydora socialis	Annelida	0.3		0.7	1.5	0.7		1.0
Dipolydora sp	Annelida							<0.1
Dougaloplus amphacanthus	Echinodermata	0.5		2.5		0.5	1.5	0.1
Dougaloplus sp A	Echinodermata	0.3				0.2		<0.1
Dougaloplus sp	Echinodermata	0.5		0.8				
Drilonereis falcata	Annelida					0.5	1.5	<0.1
Drilonereis longa	Annelida			1.5				<0.1
Drilonereis sp	Annelida	0.3		1.0		1.2		0.1
Echinoidea	Echinodermata			0.2				
Eclysippe trilobata	Annelida	1.8		1.7		1.8	5.0	1.8
Edwardsia sp G	Cnidaria			0.2			1.0	
Edwardsiidae	Cnidaria			0.2				
Elasmopus sp	Arthropoda							<0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Ennucula tenuis	Mollusca		3.5	6.7	10.5	8.2	2.0	2.9
Enopla	Nemertea			0.7				
Enteropneusta	Chordata			0.2		0.2		0.1
Epitonium hindsii	Mollusca						0.5	
Eranno bicirrata	Annelida					0.2		<0.1
Eranno lagunae	Annelida		1.5			1.0		0.1
Eranno sp	Annelida		1.0					
Eteone leptotes	Annelida					0.2		
Eteone pigmentata	Annelida			0.3				<0.1
Euchone arenae	Annelida			0.5				<0.1
Euchone incolor	Annelida	0.3	4.0	1.7		1.8	0.5	2.1
Euchone sp A	Annelida					0.2		<0.1
Euchone sp	Annelida	0.3						0.1
Euclymeninae sp A	Annelida	0.3		0.7	1.0			1.2
Euclymeninae	Annelida	0.3	2.0	0.3		0.8	0.5	1.5
Eudorella pacifica	Arthropoda				0.5			0.1
Eudorellopsis longirostris	Arthropoda			0.5			0.5	<0.1
Eulalia sp SD4	Annelida							<0.1
Eunice americana	Annelida							0.1
Euphilomedes carcharodonta	Arthropoda	3.5	6.5	0.8	1.0	2.7	1.5	7.8
Euphilomedes producta	Arthropoda	10.3	4.5	7.0	3.5	4.0	19.0	12.8
Euphysa sp A	Cnidaria		0.5					
Eurydice caudata	Arthropoda					0.2		
Exogone lourei	Annelida	0.3	0.5	0.8		1.0		
Eyakia robusta	Arthropoda	2.8		3.2	3.0	2.2		0.8
Falcidens longus	Mollusca			0.2	0.5			0.1
Fauveliopsis sp SD1	Annelida	10.0	0.5	0.3				
Foxiphalus obtusidens	Arthropoda	0.5		0.3				<0.1
Foxiphalus similis	Arthropoda	0.8	0.5	1.0		0.7	1.5	0.4
Gammaropsis martesia	Arthropoda							0.2
Gammaropsis ociosa	Arthropoda	0.5	2.0					<0.1
Gastropteron pacificum	Mollusca			0.3	0.5			0.2
Gitana calitemplado	Arthropoda		0.5					
Glycera americana	Annelida			0.2				0.1
Glycera nana	Annelida	1.8	6.5	2.0	2.0	3.7	2.0	2.3
Glycinde armigera	Annelida	1.3	0.5	0.2	1.5	1.0	1.0	0.8
Goniada brunnea	Annelida			0.2		0.3		0.3
Goniada maculata	Annelida	1.0	0.5	0.8	0.5	1.0	1.0	0.8
Gymnonereis crosslandi	Annelida			0.7				
Halcampa decemtentaculata	Cnidaria							0.1
Halianthella sp A	Cnidaria			0.2		0.2		<0.1
Halicoides synopiae	Arthropoda	0.8		0.7	3.0	1.5	1.0	0.6

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Haliophasma geminatum	Arthropoda	0.3	1.5	1.2		0.3		0.3
Hartmanodes sp	Arthropoda							<0.1
Hemilamprops californicus	Arthropoda							0.1
Heteronemertea sp SD2	Nemertea							<0.1
Heteronemertea	Nemertea			0.5		0.2		<0.1
Heterophoxus ellisi	Arthropoda		1.0	0.8	2.5			0.1
Heterophoxus oculatus	Arthropoda		1.0		0.5	1.2	0.5	1.9
Heterophoxus sp	Arthropoda		0.5	0.2				<0.1
Heterospio catalinensis	Annelida						0.5	0.1
Hiatella arctica	Mollusca			0.2				
Hippomedon columbianus	Arthropoda							0.1
Hippomedon sp A	Arthropoda	0.5		0.2		0.2		<0.1
Hippomedon zetesimus	Arthropoda		0.5					<0.1
Hoplonemertea sp A	Nemertea							<0.1
Huxleyia munita	Mollusca	3.3	1.0	0.5		0.8		0.5
Janiralata sp A	Arthropoda		0.5					
Janiralata sp	Arthropoda		0.5					
Jasmineira sp B	Annelida			0.3		0.3	1.0	<0.1
Kurtzina beta	Mollusca		1.0	0.5	0.5	0.3	0.5	0.3
Lanassa venusta venusta	Annelida	0.5	1.5	0.5		0.2		0.4
Laonice cirrata	Annelida				0.5	0.8		0.1
Laonice nuchala	Annelida	0.5		1.3		0.2		
Leitoscoloplos sp A	Annelida						0.5	
Leptochelia dubia	Arthropoda	2.5	1.5	1.2		1.3	4.0	2.2
Leptostylis abditis	Arthropoda			0.5				
Leptosynapta sp	Echinodermata	1.0	0.5	2.8		1.8	2.0	0.5
Levinsenia gracilis	Annelida		1.5	1.3	1.0	1.2		1.3
Levinsenia sp B	Annelida	0.5		2.7		0.7		0.3
Lineidae	Nemertea	0.3	1.0	1.0	0.5	0.2		0.5
Lineus bilineatus	Nemertea					0.2		0.1
Lirobittium larum	Mollusca	9.3					2.5	0.1
Listriella goleta	Arthropoda		0.5					0.1
Lucinoma annulatum	Mollusca	0.5	3.0		1.0	0.3	0.5	0.4
Lumbrineridae group III	Annelida				1.0	0.5	0.5	<0.1
Lumbrineris cruzensis	Annelida	1.3	13.5	3.0	1.5	3.7	0.5	5.7
Lumbrineris latreilli	Annelida			0.2				0.6
Lumbrineris limicola	Annelida							0.3
Lumbrineris lingulata	Annelida	1.0		0.3				0.1
Lumbrineris sp group I	Annelida	0.5	11.0	4.3	3.0	5.7		4.5
Lumbrineris sp group II	Annelida			3.2				0.1
Lysippe sp A	Annelida	2.8	0.5	8.0	1.0	2.8	4.5	4.6
Lysippe sp B	Annelida	1.3	1.5	2.3		1.2	2.0	1.3

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Lytechinus pictus	Echinodermata			0.3		0.3		0.2
Macoma carlottensis	Mollusca							0.2
Macoma nasuta	Mollusca							<0.1
Macoma sp	Mollusca		0.5	0.2		0.2	0.5	0.1
Magelona berkeleyi	Annelida	0.8						
Magelona sp B	Annelida	0.5						
Malacoceros indicus	Annelida			0.2				<0.1
Maldane sarsi	Annelida	0.5	1.5	0.3	0.5	2.2		1.0
Maldanidae	Annelida		6.0	1.2		1.3	0.5	0.9
Malmgreniella baschi	Annelida			0.2				<0.1
Malmgreniella sanpedroensis	Annelida		0.5	0.5		0.2	1.0	0.1
Malmgreniella scriptoria	Annelida							<0.1
Malmgreniella sp A	Annelida							<0.1
Malmgreniella sp	Annelida	0.8		1.0	1.5	1.2	0.5	0.5
Mayerella banksia	Arthropoda	1.0		0.8		0.2		<0.1
Mediomastus sp	Annelida	6.3	24.5	39.2	9.0	10.8	6.5	13.1
Megalomma pigmentum	Annelida						0.5	
Megalomma sp	Annelida	0.3		0.2				
Megalomma splendida	Annelida							<0.1
Megasurcula carpenteriana	Mollusca		1.0			0.2		<0.1
Melanella rosa	Mollusca							<0.1
Melinna oculata	Annelida							0.1
Melitidae	Arthropoda		0.5					
Melphisana bola complex	Arthropoda					0.2		<0.1
Mesolamprops bispinosus	Arthropoda							<0.1
Metaphoxus frequens	Arthropoda	0.3		0.2	0.5			<0.1
Micranellum crebricinctum	Mollusca	9.5		0.3				
Micrura alaskensis	Nemertea							<0.1
Micrura sp	Nemertea							<0.1
Molgula napiformis	Chordata			0.5		0.5		0.3
Molgula pugetiensis	Chordata			0.2		0.7		0.1
Molgula regularis	Chordata				0.5			
Molgula sp	Chordata		0.5					0.1
Monoculodes emarginatus	Arthropoda	2.8	1.0	2.0		1.2	1.5	1.7
Monostyliferoidea	Nemertea	0.3						<0.1
Monticellina cryptica	Annelida			3.0	3.0	0.8	3.0	1.3
Monticellina siblina	Annelida	3.8		5.7		2.3	2.0	1.1
Monticellina sp SD7	Annelida			1.0			0.5	0.2
Monticellina sp	Annelida					0.3		
Monticellina tesselata	Annelida	0.3		0.2		0.2	0.5	0.1
Mooreonuphis exigua	Annelida	1.5						
Mooreonuphis nebulosa	Annelida			0.3				

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Mooreonuphis segmentispadix	Annelida	0.3						
Mooreonuphis sp SD1	Annelida	0.3		0.2			0.5	
Mooreonuphis sp	Annelida	1.0		0.2				
Myriochele gracilis	Annelida			0.7	0.5	1.2	1.5	0.6
Myriochele striolata	Annelida							<0.1
Myriowenia californiensis	Annelida	0.3						
Myxicola sp	Annelida			0.2				
Nematoda	Nematoda							<0.1
Nemertea	Nemertea							<0.1
Nassariidae	Mollusca							<0.1
Neaeromya compressa	Mollusca							0.2
Neastacilla californica	Arthropoda		4.0	0.3				<0.1
Nebalia pugettensis complex	Arthropoda			0.2				
Nemocardium centifilosum	Mollusca			0.2				<0.1
Neocrangon zacae	Arthropoda							<0.1
Neosabellaria cementarium	Annelida		1.0					
Nephtys caecoides	Annelida					0.2		0.3
Nephtys cornuta	Annelida					0.2		<0.1
Nephtys ferruginea	Annelida	1.8	1.5	1.8	1.0	0.3	4.5	1.0
Nereiphylla sp 2	Annelida			0.2				0.1
Nereis sp A	Annelida							0.1
Nicippe tumida	Arthropoda	0.5		1.5	0.5	0.3		0.5
Notocirrus californiensis	Annelida					0.3		0.1
Notomastus latericeus	Annelida					0.2	0.5	<0.1
Notomastus magnus	Annelida							<0.1
Notomastus sp A	Annelida	0.8	12.5	1.2		1.7	1.0	0.5
Nuculana hamata	Mollusca		2.5	0.2				<0.1
Nuculana sp A	Mollusca	0.5	1.5	0.7		0.2		0.9
Odostomia sp	Mollusca					0.3		0.3
Oedicerotidae	Arthropoda							<0.1
Oerstedia dorsalis	Nemertea		0.5	0.2				
Onuphidae	Annelida	0.3					0.5	
Onuphis affinis	Annelida	0.3						
Onuphis iridescens	Annelida							<0.1
Onuphis sp A	Annelida			0.5				0.2
Onuphis sp	Annelida	1.5		0.5				0.2
Ophelina acuminata	Annelida	0.8	0.5					
Ophelina sp SD1	Annelida						0.5	
Ophiopholis bakeri	Echinodermata							<0.1
Ophiura luetkenii	Echinodermata		0.5	0.3				0.1
Ophiuroconis bispinosa	Echinodermata			1.3	0.5			
Ophiuroidea	Echinodermata			0.5			0.5	0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Orchomenella decipiens	Arthropoda							<0.1
Orchomenella pinguis	Arthropoda			0.2				<0.1
Owenia collaris	Annelida							<0.1
Pachynus barnardi	Arthropoda							<0.1
Paguristes turgidus	Arthropoda	0.5						
Palaeonemertea	Nemertea		0.5					<0.1
Pandora bilirata	Mollusca			0.2	0.5	0.2		0.2
Paradiopatra parva	Annelida	1.8	1.0	0.8	1.0	1.7	6.0	1.6
Paradoneis sp	Annelida							<0.1
Paramage scutata	Annelida		0.5				0.5	0.1
Paranaitis polynoides	Annelida	0.3						
Paranaitis sp SD1	Annelida							<0.1
Parandalia fauveli	Annelida			0.2				
Paranemertes californica	Nemertea		0.5	0.3		0.2		0.2
Paraonidae	Annelida	1.3	0.5	0.2		0.2		0.2
Paraprionospio alata	Annelida			0.2		0.2	2.0	0.5
Parvilucina tenuisculpta	Mollusca	2.8	4.0	0.3	0.5		6.0	1.2
Pectinaria californiensis	Annelida		1.0	1.5	1.0	0.8	2.0	1.6
Pentamera populifera	Echinodermata			0.2			0.5	
Petaloclymene pacifica	Annelida						1.5	0.3
Phascolion sp A	Sipuncula	0.8	0.5	0.8		0.7	0.5	0.3
Pherusa negligens	Annelida	0.3						<0.1
Pherusa neopapillata	Annelida	0.3		0.5				<0.1
Pherusa sp	Annelida	0.3						
Philine auriformis	Mollusca							<0.1
Philine californica	Mollusca							<0.1
Phisidia sanctaemariae	Annelida	1.5	3.5	3.3	1.5	2.8	2.5	2.0
Pholoe glabra	Annelida	1.8	1.0	1.7	4.0	0.7	1.5	1.4
Pholoides asperus	Annelida					0.3		<0.1
Phoronis sp	Phorona		0.5	0.3		0.3		0.1
Photis bifurcata	Arthropoda		2.0					0.2
Photis brevipes	Arthropoda		2.5					
Photis californica	Arthropoda		28.0	1.5		0.5		
Photis lacia	Arthropoda	3.0	0.5	0.2		0.8		0.2
Photis parvidons	Arthropoda				1.0	0.3		0.1
Photis sp C	Arthropoda	0.3	0.5	0.2		0.2		0.4
Photis sp	Arthropoda		1.5					
Phoxocephalidae	Arthropoda							0.1
Phyllodoce cuspidata	Annelida			0.2	0.5			<0.1
Phyllodoce groenlandica	Annelida	0.5		0.5		0.2		0.1
Phyllodoce hartmanae	Annelida		1.5			0.2	0.5	<0.1
Phyllodoce longipes	Annelida		0.5	0.3				0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Phyllodoce medipapillata	Annelida		0.5					
Pinnixa occidentalis complex	Arthropoda			0.5	0.5	0.5		0.1
Pinnixa sp	Arthropoda				1.5			0.1
Pionosyllis articulata	Annelida					0.2		0.1
Piromis sp A	Annelida					0.2		
Pista brevibranchiata	Annelida		1.5					
Pista estevanica	Annelida		1.0	0.5		0.2	2.0	0.4
Pista moorei	Annelida	0.3						<0.1
Pista sp	Annelida			0.2			0.5	
Pista wui	Annelida			1.2			0.5	0.2
Platymera gaudichaudii	Arthropoda							<0.1
Pleurogonium californiense	Arthropoda							<0.1
Podarkeopsis glabrus	Annelida			0.2	1.0	0.2	0.5	0.1
Polycirrus californicus	Annelida							<0.1
Polycirrus sp A	Annelida	1.5		4.5		2.8		2.3
Polycirrus sp I	Annelida	14.0	31.5	6.7	1.0	8.8	38.0	9.9
Polycirrus sp OC1	Annelida						0.5	0.1
Polycirrus sp	Annelida			0.3				
Polyschides quadrifissatus	Mollusca	1.5		0.5	1.5	0.5		0.7
Prachynella lodo	Arthropoda					0.3		<0.1
Praxillella pacifica	Annelida	0.8	6.0	1.2	0.5	0.8	1.0	3.9
Prionospio (*Minuspio*) *lighti*	Annelida	0.3		0.5	0.5	0.2		0.2
Prionospio (*Prionospio*) *dubia*	Annelida	4.8	3.5	6.3	2.5	6.5	6.5	4.5
Prionospio (*Prionospio*) *jubata*	Annelida	10.3	2.5	5.2	1.0	5.8	2.5	5.2
Procampylaspis caenosa	Arthropoda	0.3		0.8		0.3		<0.1
Proclea sp A	Annelida	0.5		0.3	1.5	2.2	1.5	2.9
Protocirrineris sp A	Annelida	0.3				0.2		
Protomedeia articulata complex	Arthropoda			0.2	0.5			1.0
Rhachotropis sp A	Arthropoda	0.3		0.3	1.5	1.0		0.3
Rhepoxynius bicuspidatus	Arthropoda	0.3	1.0	1.5	3.0	3.3	1.0	4.3
Rhepoxynius menziesi	Arthropoda		0.5				0.5	1.0
Rhepoxynius sp	Arthropoda							<0.1
Rhepoxynius stenodes	Arthropoda							<0.1
Rhodine bitorquata	Annelida	0.8	1.0	0.5	0.5	1.3	1.0	1.3
Rictaxis punctocaelatus	Mollusca	1.3	0.5	0.3			1.0	0.3
Rochefortia tumida	Mollusca		0.5	0.7	2.0	0.3		<0.1
Sabellidae	Annelida		0.5					<0.1
Samytha californiensis	Annelida					0.2		0.1
Saxicavella pacifica	Mollusca							0.1
Scalibregma californicum	Annelida	0.3		0.7		0.3	0.5	0.1
Scleroconcha trituberculata	Arthropoda			0.2				<0.1
Scolelepis (*Parascolelepis*) sp SD1	Annelida					0.2		

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Scoletoma tetraura complex	Annelida			1.0	1.5	0.3		0.2
Scoloplos armiger complex	Annelida	5.5	1.5	0.7		0.8	4.0	3.2
Scoloplos sp	Annelida	0.3		0.5				
Scoloura phillipsi	Arthropoda	0.8					1.0	<0.1
Sigalion spinosus	Annelida	0.5					0.5	0.5
Sige sp A	Annelida							<0.1
Sige sp	Annelida							<0.1
Sinum scopulosum	Mollusca			0.3				<0.1
Siphonolabrum californiensis	Arthropoda							0.5
Solamen columbianum	Mollusca	0.5				1.5		<0.1
Solariella peramabilis	Mollusca	0.8		0.2				0.1
Solemya pervernicosa	Mollusca							0.1
Sosane occidentalis	Annelida		0.5	0.2				0.1
Sphaeromatidae	Arthropoda			0.2				<0.1
Spio filicornis	Annelida	0.3	0.5	0.2		0.5	0.5	0.3
Spio maculata	Annelida	0.3						0.1
Spiochaetopterus costarum complex	Annelida							<0.1
Spiophanes berkeleyorum	Annelida	0.5	1.0	1.0	3.5	0.5	8.5	6.1
Spiophanes duplex	Annelida	0.3		0.5		0.3	1.0	0.5
Spiophanes kimballi	Annelida	0.3	0.5		0.5	0.2		0.5
Spiophanes norrisi	Annelida	0.3		0.2		0.3		0.2
Stenothoe frecanda	Arthropoda		0.5					
Stereobalanus sp	Chordata			0.5	4.0	0.5		0.1
Sternaspis fossor	Annelida	1.3	6.0	3.3	4.5	3.0	7.0	5.0
Sthenelais tertiaglabra	Annelida	2.5		0.8	1.0	0.5	13.5	0.9
Sthenelanella uniformis	Annelida		0.5	0.2	0.5	0.3	0.5	0.2
Styela sp	Chordata		0.5					
Stylatula sp	Cnidaria					0.2		<0.1
Subadyte mexicana	Annelida			0.3				
Synidotea magnifica	Arthropoda			0.2				
Tanaella propinquus	Arthropoda			0.7	0.5	1.8		1.8
Tanaidacea	Arthropoda							0.2
Tanaopsis cadieni	Arthropoda			1.0		0.5	1.5	0.8
Tellina cadieni	Mollusca		0.5	0.5			0.5	0.5
Tellina carpenteri	Mollusca	4.0	4.5	4.0	1.0	0.8	6.0	2.2
Tellinidae	Mollusca							<0.1
Tenonia priops	Annelida	0.3	1.0					<0.1
Terebellidae	Annelida							<0.1
Terebellides californica	Annelida	1.8	2.0	4.5	3.0	2.7	4.5	5.0
Terebellides reishi	Annelida				0.5		0.5	0.3
Terebellides sp Type D	Annelida			0.7		1.2	0.5	0.3
Terebellides sp	Annelida			0.2				<0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Tetrastemma candidum	Nemertea			0.3				
Thelepus hamatus	Annelida		0.5					
Thracia trapezoides	Mollusca			0.2	0.5			<0.1
Thyasira flexuosa	Mollusca							0.1
Thysanocardia nigra	Sipuncula			0.2				<0.1
Travisia brevis	Annelida	0.3	0.5	1.0	4.5	4.3	0.5	2.4
Tritella pilimana	Arthropoda		0.5					
Tubulanus cingulatus	Nemertea				0.5		0.5	0.2
Tubulanus polymorphus	Nemertea							<0.1
Tubulanus sp A	Nemertea							<0.1
Tubulanus sp	Nemertea			0.3				<0.1
Turbonilla sp SD1	Mollusca					0.2		<0.1
Turbonilla sp SD5	Mollusca		0.5					0.2
Turbonilla sp	Mollusca	0.3	1.0					<0.1
Typhlotanais sp	Arthropoda							<0.1
Typhlotanais williamsi	Arthropoda							0.1
Typosyllis heterochaeta	Annelida		1.0	0.3		0.7		0.2
Urothoe elegans complex	Arthropoda	6.0		1.0		0.2	0.5	0.1
Virgulariidae	Cnidaria							<0.1
Volvulella cylindrica	Mollusca				1.0	0.3		0.2
Volvulella panamica	Mollusca							<0.1
Volvulella sp	Mollusca							<0.1
Westwoodilla tone	Arthropoda	1.3		0.5	0.5	0.3	1.5	0.4
Xenoleberis californica	Arthropoda		0.5	0.7			0.5	0.1
Zygeupolia rubens	Nemertea				0.5			

Appendix E

Supporting Data

2009 PLOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Summary of demersal fish species captured during 2009 at PLOO trawl stations. Data are number of fish (*n*), biomass (BM; kg, wet weight), minimum (Min), maximum (Max), and mean length (cm, standard length). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Allen (2005).

				Length		
Taxon/Species	**Common Name**	***n***	**BM**	**Min**	**Max**	**Mean**
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California lizardfish	177	1.4	7	20	10
OPHIDIIFORMES						
Ophidiidae						
Chilara taylori	Spotted cuskeel	7	0.4	15	20	17
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys notatus	Plainfin midshipman	29	1.1	6	15	12
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California scorpionfish	8	3.3	19	25	22
Sebastes elongatus	Greenstriped rockfish	12	0.5	4	11	7
Sebastes rubrivinctus	Flag rockfish	1	0.1	7	7	7
Sebastes saxicola	Stripetail rockfish	16	0.5	8	12	9
Sebastes semicinctus	Halfbanded rockfish	125	3.0	8	14	10
Hexagrammidae						
Zaniolepis frenata	Shortspine combfish	79	1.9	8	16	12
Zaniolepis latipinnis	Longspine combfish	102	2.6	7	15	13
Cottidae						
Chitonotus pugetensis	Roughback sculpin	5	0.3	8	10	9
Icelinus quadriseriatus	Yellowchin sculpin	11	0.2	6	7	6
Icelinus tenuis	Spotfin sculpin	1	0.1	9	9	9
PERCIFORMES						
Sciaenidae						
Genyonemus lineatus	White croaker	2	0.3	20	21	21
Embiotocidae						
Zalembius rosaceus	Pink seaperch	38	1.3	5	13	10
Bathymasteridae						
Rathbunella hypoplecta	Bluebanded ronquil	1	0.1	12	12	12
Anarhichadidae						
Anarrhichthys ocellatus	Wolf-eel	1	2.5	105	105	105
Uranoscopidae						
Kathetostoma averruncus	Smooth stargazer	1	0.1	8	8	8
PLEURONECTIFORMES						
Paralichthyidae						
Citharichthys sordidus	Pacific sanddab	816	20.9	3	26	10
Citharichthys xanthostigma	Longfin sanddab	2	0.2	14	20	17
Hippoglossina stomata	Bigmouth sole	5	0.9	15	28	20
Pleuronectidae						
Eopsetta exilis	Slender sole	26	0.8	12	16	14
Microstomus pacificus	Dover sole	106	3.7	5	20	11
Parophrys vetulus	English sole	50	3.5	9	20	16
Pleuronichthys verticalis	Hornyhead turbot	13	1.3	13	18	15
Cynoglossidae						
Symphurus atricauda	California tonguefish	11	0.4	12	16	14

Appendix E.2

Summary of total abundance by species and station for demersal fishes at the PLOO trawl stations during 2009.

	January 2009		Species Abundance by Survey
Name	SD10	SD12	
Pacific sanddab	130	27	157
Halfbanded rockfish	36	7	43
Longspine combfish	14	28	42
English sole	8	24	32
Shortspine combfish	5	19	24
Dover sole	3	9	12
California scorpionfish		8	8
California tonguefish	4	4	8
Hornyhead turbot	2	6	8
Plainfin midshipman	2	6	8
Yellowchin sculpin	8		8
Greenstriped rockfish	2	4	6
Pink seaperch	4		4
Stripetail rockfish	2		2
Longfin sanddab	1		1
Smooth stargazer		1	1
Wolf-eel	1		1
Winter Total	222	143	365

Appendix E.2 *continued*

Name	July 2009						Species Abundance by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Pacific sanddab	120	103	62	149	58	167	659
California lizardfish	7	17	26	73	29	25	177
Dover sole	9	3	2	57	4	19	94
Halfbanded rockfish	1	21	4	14	22	20	82
Longspine combfish	8	8	1	32	2	9	60
Shortspine combfish	9	15	1	22	2	6	55
Pink seaperch	1	1		2	12	18	34
Slender sole		2	2	10	5	7	26
Plainfin midshipman	1	3	3	7	1	6	21
English sole		4	1	1	3	9	18
Stripetail rockfish	1	1			9	3	14
Spotted cuskeel	1	1		4	1		7
Greenstriped rockfish			2	2	2		6
Bigmouth sole		1				4	5
Hornyhead turbot				2	1	2	5
Roughback sculpin		2	1	2			5
California tonguefish	2	1					3
Yellowchin sculpin	3						3
White croaker			2				2
Bluebanded ronquil		1					1
Flag rockfish			1				1
Longfin sanddab						1	1
Spotfin sculpin		1					1
Summer Total	163	185	108	377	151	296	1280

Appendix E.3

Summary of biomass (kg) by species and station for demersal fishes at the PLOO trawl stations during 2009.

	January 2009		Biomass
Name	SD10	SD12	by Survey
Pacific sanddab	4.3	1.4	5.7
California scorpionfish		3.3	3.3
Wolf-eel	2.5		2.5
English sole	0.6	1.3	1.9
Halfbanded rockfish	0.8	0.3	1.1
Longspine combfish	0.3	0.7	1.0
Hornyhead turbot	0.2	0.6	0.8
Shortspine combfish	0.1	0.3	0.4
Dover sole	0.1	0.2	0.3
Plainfin midshipman	0.1	0.2	0.3
California tonguefish	0.1	0.1	0.2
Greenstriped rockfish	0.1	0.1	0.2
Pink seaperch	0.2		0.2
Longfin sanddab	0.1		0.1
Smooth stargazer		0.1	0.1
Stripetail rockfish	0.1		0.1
Yellowchin sculpin	0.1		0.1
Winter Total	9.7	8.6	18.3

Appendix E.3 *continued*

Name	July 2009						Biomass by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Pacific sanddab	2.3	2.3	2.0	2.1	2.0	4.5	15.2
Dover sole	0.7	0.2	0.1	1.1	0.1	1.2	3.4
Halfbanded rockfish	0.1	0.4	0.1	0.1	0.6	0.6	1.9
English sole		0.4	0.1	0.1	0.4	0.6	1.6
Longspine combfish	0.3	0.2	0.1	0.7	0.1	0.2	1.6
Shortspine combfish	0.2	0.5	0.1	0.5	0.1	0.1	1.5
California lizardfish	0.1	0.1	0.2	0.5	0.2	0.3	1.4
Pink seaperch	0.1	0.1		0.1	0.2	0.6	1.1
Bigmouth sole		0.5				0.4	0.9
Plainfin midshipman	0.1	0.1	0.1	0.1	0.1	0.3	0.8
Slender sole		0.1	0.1	0.4	0.1	0.1	0.8
Hornyhead turbot				0.2	0.2	0.1	0.5
Spotted cuskeel	0.1	0.1		0.1	0.1		0.4
Stripetail rockfish	0.1	0.1			0.1	0.1	0.4
White croaker			0.3				0.3
Greenstriped rockfish			0.1	0.1	0.1		0.3
Roughback sculpin		0.1	0.1	0.1			0.3
California tonguefish	0.1	0.1					0.2
Bluebanded ronquil		0.1					0.1
Flag rockfish			0.1				0.1
Longfin sanddab						0.1	0.1
Spotfin sculpin		0.1					0.1
Yellowchin sculpin	0.1						0.1
Summer Total	4.3	5.5	3.5	6.2	4.4	9.2	33.1

Appendix E.4

Summary of the species that distinguish between each cluster group according to SIMPER analyses (i.e., average dissimilarity ≥ 1.5). Values are average abundances for each group being compared (i.e., Group "X" vs Group "Y") and the average dissimilarities between groups for each species.

	Average Abundance		Average Dissimilarity
	Group "X"	**Group "Y"**	
Cluster Groups H & G	Group H	Group G	
Pacific sanddab	15.25	11.67	4.49
halfbanded rockfish	1.78	5.57	4.37
yellowchin sculpin	3.44	0.51	3.31
shortspine combfish	1.04	3.19	2.37
stripetail rockfish	2.59	0.97	2.36
longspine combfish	2.84	2.98	2.33
Dover sole	5.04	4.78	2.16
slender sole	1.53	2.10	1.89
plainfin midshipman	2.35	1.60	1.85
California lizardfish	0.12	1.59	1.69
longfin sanddab	1.62	0.13	1.67
Cluster Groups H & C	Group H	Group C	
Pacific sanddab	15.25	7.20	11.32
yellowchin sculpin	3.44	0.00	4.88
Dover sole	5.04	2.02	4.23
stripetail rockfish	2.59	1.29	3.44
longspine combfish	2.84	1.24	2.65
California lizardfish	0.12	1.70	2.35
halfbanded rockfish	1.78	0.67	2.30
longfin sanddab	1.62	0.47	2.22
pink seaperch	1.67	0.58	2.11
plainfin midshipman	2.35	1.38	2.06
slender sole	1.53	0.80	1.95
bay goby	1.11	0.00	1.57
Cluster Groups G & C	Group G	Group C	
halfbanded rockfish	5.57	0.67	6.59
Pacific sanddab	11.67	7.20	6.14
shortspine combfish	3.19	0.33	4.07
Dover sole	4.78	2.02	3.84
California lizardfish	1.59	1.70	3.26
longspine combfish	2.98	1.24	2.66
stripetail rockfish	0.97	1.29	2.31
slender sole	2.10	0.80	2.27
pink seaperch	1.88	0.58	2.11
English sole	1.59	0.33	1.89
plainfin midshipman	1.60	1.38	1.47

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups H & F	Group H	Group F	
Pacific sanddab	15.25	9.59	7.40
yellowchin sculpin	3.44	1.47	3.12
stripetail rockfish	2.59	1.80	3.06
Dover sole	5.04	3.00	2.98
longspine combfish	2.84	0.53	2.98
plainfin midshipman	2.35	2.53	2.88
longfin sanddab	1.62	2.31	2.38
halfbanded rockfish	1.78	0.94	1.97
pink seaperch	1.67	0.55	1.88
slender sole	1.53	0.57	1.77
California tonguefish	0.46	1.47	1.66
Cluster Groups G & F	Group G	Group F	
halfbanded rockfish	5.57	0.94	5.55
Pacific sanddab	11.67	9.59	3.90
longspine combfish	2.98	0.53	3.17
shortspine combfish	3.19	1.07	2.77
longfin sanddab	0.13	2.31	2.76
Dover sole	4.78	3.00	2.63
plainfin midshipman	1.60	2.53	2.62
slender sole	2.10	0.57	2.19
stripetail rockfish	0.97	1.80	2.18
California lizardfish	1.59	0.27	2.02
pink seaperch	1.88	0.55	1.88
yellowchin sculpin	0.51	1.47	1.83
greenstriped rockfish	1.36	0.19	1.60
California tonguefish	0.87	1.47	1.60
English sole	1.59	0.51	1.58
Cluster Groups C & F	Group C	Group F	
Pacific sanddab	7.20	9.59	4.78
stripetail rockfish	1.29	1.80	3.74
longfin sanddab	0.47	2.31	3.44
plainfin midshipman	1.38	2.53	3.35
California lizardfish	1.70	0.27	3.06
California tonguefish	0.00	1.47	2.66
yellowchin sculpin	0.00	1.47	2.63
Dover sole	2.02	3.00	2.16
greenstriped rockfish	1.14	0.19	1.90
halfbanded rockfish	0.67	0.94	1.83

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	**Group "Y"**	
Cluster Groups C & F *continued*	Group C	Group F	
spotfin sculpin	0.58	0.67	1.79
shortspine combfish	0.33	1.07	1.77
longspine combfish	1.24	0.53	1.61
Cluster Groups H & A	Group H	Group A	
Pacific sanddab	15.25	4.80	17.01
Dover sole	5.04	0.00	8.11
yellowchin sculpin	3.44	0.00	5.61
halfbanded rockfish	1.78	4.00	4.51
longspine combfish	2.84	0.00	4.40
stripetail rockfish	2.59	0.00	3.98
plainfin midshipman	2.35	0.00	3.69
longfin sanddab	1.62	1.00	2.42
slender sole	1.53	0.00	2.31
pink seaperch	1.67	1.00	1.99
bay goby	1.11	0.00	1.80
shortspine combfish	1.04	0.00	1.73
spotfin sculpin	0.06	1.00	1.70
gulf sanddab	0.23	1.00	1.60
Cluster Groups G & A	Group G	Group A	
Pacific sanddab	11.67	4.80	11.00
Dover sole	4.78	0.00	7.65
shortspine combfish	3.19	0.00	5.19
longspine combfish	2.98	0.00	4.85
halfbanded rockfish	5.57	4.00	4.36
slender sole	2.10	0.00	3.39
plainfin midshipman	1.60	0.00	2.61
California lizardfish	1.59	0.00	2.57
English sole	1.59	0.00	2.52
greenstriped rockfish	1.36	0.00	2.17
spotfin sculpin	0.73	1.00	1.68
greenspotted rockfish	0.00	1.00	1.66
gulf sanddab	0.00	1.00	1.66
longfin sanddab	0.13	1.00	1.59
hornyhead turbot	1.00	0.00	1.56
stripetail rockfish	0.97	0.00	1.53
California tonguefish	0.87	0.00	1.47

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups C & A	Group C	Group A	
halfbanded rockfish	0.67	4.00	9.36
Pacific sanddab	7.20	4.80	6.62
Dover sole	2.02	0.00	5.59
California lizardfish	1.70	0.00	4.13
plainfin midshipman	1.38	0.00	3.77
stripetail rockfish	1.29	0.00	3.48
longspine combfish	1.24	0.00	3.40
greenstriped rockfish	1.14	0.00	3.08
greenspotted rockfish	0.00	1.00	2.74
pink seaperch	0.58	1.00	2.50
spotfin sculpin	0.58	1.00	2.47
greenblotched rockfish	0.80	0.00	2.36
longfin sanddab	0.47	1.00	2.22
slender sole	0.80	0.00	2.04
Cluster Groups F & A	Group F	Group A	
Pacific sanddab	9.59	4.80	10.06
halfbanded rockfish	0.94	4.00	6.98
Dover sole	3.00	0.00	6.57
plainfin midshipman	2.53	0.00	5.32
stripetail rockfish	1.80	0.00	3.63
California tonguefish	1.47	0.00	3.19
yellowchin sculpin	1.47	0.00	3.15
longfin sanddab	2.31	1.00	2.90
spotfin sculpin	0.67	1.00	2.60
shortspine combfish	1.07	0.00	2.31
greenspotted rockfish	0.27	1.00	1.94
pink seaperch	0.55	1.00	1.85
gulf sanddab	0.21	1.00	1.83
bay goby	0.74	0.00	1.49
Cluster Groups H & E	Group H	Group E	
halfbanded rockfish	1.78	7.75	6.57
squarespot rockfish	0.00	4.80	5.18
Pacific sanddab	15.25	10.49	5.07
Dover sole	5.04	1.00	4.25
yellowchin sculpin	3.44	0.00	3.67
vermilion rockfish	0.00	2.45	2.65
greenblotched rockfish	0.81	2.83	2.19
stripetail rockfish	2.59	2.24	1.91

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups H & E *continued*	Group H	Group E	
longspine combfish	2.84	1.41	1.88
longfin sanddab	1.62	0.00	1.70
slender sole	1.53	0.00	1.55
plainfin midshipman	2.35	2.00	1.45
Cluster Groups G & E	Group G	Group E	
squarespot rockfish	0.09	4.80	5.07
halfbanded rockfish	5.57	7.75	4.61
Dover sole	4.78	1.00	3.96
greenblotched rockfish	0.29	2.83	2.76
vermilion rockfish	0.00	2.45	2.64
slender sole	2.10	0.00	2.23
Pacific sanddab	11.67	10.49	2.09
longspine combfish	2.98	1.41	1.83
stripetail rockfish	0.97	2.24	1.74
California lizardfish	1.59	0.00	1.69
shortspine combfish	3.19	1.73	1.63
Cluster Groups C & E	Group C	Group E	
halfbanded rockfish	0.67	7.75	10.39
squarespot rockfish	0.00	4.80	7.00
Pacific sanddab	7.20	10.49	4.79
vermilion rockfish	0.00	2.45	3.58
stripetail rockfish	1.29	2.24	2.97
greenblotched rockfish	0.80	2.83	2.91
California lizardfish	1.70	0.00	2.33
shortspine combfish	0.33	1.73	2.07
greenstriped rockfish	1.14	0.00	1.65
Dover sole	2.02	1.00	1.50
California tonguefish	0.00	1.00	1.46
bigmouth sole	0.00	1.00	1.46
hornyhead turbot	0.00	1.00	1.46
California scorpionfish	0.00	1.00	1.46
greenspotted rockfish	0.00	1.00	1.46
rex sole	0.00	1.00	1.46

Appendix E.4 *continued*

	Average Abundance		Average
	Group "X"	Group "Y"	Dissimilarity
Cluster Groups F & E	Group F	Group E	
halfbanded rockfish	0.94	7.75	8.83
squarespot rockfish	0.07	4.80	6.08
vermilion rockfish	0.00	2.45	3.16
greenblotched rockfish	0.49	2.83	3.05
longfin sanddab	2.31	0.00	2.93
Pacific sanddab	9.59	10.49	2.60
Dover sole	3.00	1.00	2.55
plainfin midshipman	2.53	2.00	2.31
stripetail rockfish	1.80	2.24	2.25
yellowchin sculpin	1.47	0.00	1.86
Cluster Groups A & E	Group A	Group E	
Pacific sanddab	4.80	10.49	9.57
squarespot rockfish	0.00	4.80	8.06
halfbanded rockfish	4.00	7.75	6.30
greenblotched rockfish	0.00	2.83	4.75
vermilion rockfish	0.00	2.45	4.12
stripetail rockfish	0.00	2.24	3.76
plainfin midshipman	0.00	2.00	3.36
shortspine combfish	0.00	1.73	2.91
longspine combfish	0.00	1.41	2.38
California tonguefish	0.00	1.00	1.68
longfin sanddab	1.00	0.00	1.68
Dover sole	0.00	1.00	1.68
bigmouth sole	0.00	1.00	1.68
flag rockfish	0.00	1.00	1.68
hornyhead turbot	0.00	1.00	1.68
English sole	0.00	1.00	1.68
California scorpionfish	0.00	1.00	1.68
Cluster Groups H & D	Group H	Group D	
plainfin midshipman	2.35	10.77	9.24
Pacific sanddab	15.25	8.66	6.99
yellowchin sculpin	3.44	0.00	3.69
gulf sanddab	0.23	2.24	2.31
stripetail rockfish	2.59	1.00	2.19
bigfin eelpout	0.11	2.00	2.09
Dover sole	5.04	6.00	1.98
longspine combfish	2.84	2.65	1.92
halfbanded rockfish	1.78	0.00	1.83

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups H & D *continued*	Group H	Group D	
longfin sanddab	1.62	0.00	1.71
California scorpionfish	0.06	1.41	1.48
slender sole	1.53	1.41	1.45
Cluster Groups G & D	Group G	Group D	
plainfin midshipman	1.60	10.77	9.93
halfbanded rockfish	5.57	0.00	5.67
shortspine combfish	3.19	0.00	3.41
Pacific sanddab	11.67	8.66	3.27
gulf sanddab	0.00	2.24	2.42
bigfin eel pout	0.08	2.00	2.08
Dover sole	4.78	6.00	1.79
California lizardfish	1.59	0.00	1.69
California scorpionfish	0.04	1.41	1.49
Cluster Groups C & D	Group C	Group D	
plainfin midshipman	1.38	10.77	13.79
Dover sole	2.02	6.00	5.83
bigfin eel pout	0.00	2.00	2.94
stripetail rockfish	1.29	1.00	2.38
California lizardfish	1.70	0.00	2.34
gulf sanddab	0.67	2.24	2.27
Pacific sanddab	7.20	8.66	2.14
pink seaperch	0.58	2.00	2.10
English sole	0.33	1.73	2.08
California scorpionfish	0.00	1.41	2.08
longspine combfish	1.24	2.65	2.06
greenstriped rockfish	1.14	0.00	1.66
roughback sculpin	0.33	1.41	1.62
hornyhead turbot	0.00	1.00	1.47
California skate	0.00	1.00	1.47
spotted rockfish	0.00	1.00	1.47
Pacific hake	0.00	1.00	1.47

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group “X”	Group “Y”	
Cluster Groups F & D	Group F	Group D	
plainfin midshipman	2.53	10.77	11.09
Dover sole	3.00	6.00	3.91
longfin sanddab	2.31	0.00	2.94
longspine combfish	0.53	2.65	2.77
gulf sanddab	0.21	2.24	2.63
bigfin eelpout	0.00	2.00	2.59
Pacific sanddab	9.59	8.66	2.37
pink seaperch	0.55	2.00	1.96
California tonguefish	1.47	0.00	1.88
stripetail rockfish	1.80	1.00	1.88
yellowchin sculpin	1.47	0.00	1.87
California scorpionfish	0.13	1.41	1.67
English sole	0.51	1.73	1.64
roughback sculpin	0.26	1.41	1.51
Cluster Groups A & D	Group A	Group D	
plainfin midshipman	0.00	10.77	18.23
Dover sole	0.00	6.00	10.16
halfbanded rockfish	4.00	0.00	6.77
Pacific sanddab	4.80	8.66	6.54
longspine combfish	0.00	2.65	4.48
bigfin eelpout	0.00	2.00	3.39
English sole	0.00	1.73	2.93
roughback sculpin	0.00	1.41	2.39
slender sole	0.00	1.41	2.39
California scorpionfish	0.00	1.41	2.39
gulf sanddab	1.00	2.24	2.09
longfin sanddab	1.00	0.00	1.69
pink seaperch	1.00	2.00	1.69
hornyhead turbot	0.00	1.00	1.69
stripetail rockfish	0.00	1.00	1.69
California skate	0.00	1.00	1.69
Cluster Groups E & D	Group E	Group D	
plainfin midshipman	2.00	10.77	9.64
halfbanded rockfish	7.75	0.00	8.51

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups E & D *continued*	Group E	Group D	
Dover sole	1.00	6.00	5.50
squarespot rockfish	4.80	0.00	5.27
greenblotched rockfish	2.83	0.00	3.11
vermilion rockfish	2.45	0.00	2.69
gulf sanddab	0.00	2.24	2.46
bigfin eel pout	0.00	2.00	2.20
Pacific sanddab	10.49	8.66	2.01
shortspine combfish	1.73	0.00	1.90
roughback sculpin	0.00	1.41	1.55
slender sole	0.00	1.41	1.55
Cluster Groups H & B	Group H	Group B	
Pacific sanddab	15.25	6.71	12.46
Dover sole	5.04	0.71	6.20
stripetail rockfish	2.59	0.00	3.59
plainfin midshipman	2.35	0.00	3.33
longspine combfish	2.84	1.12	3.25
yellowchin sculpin	3.44	2.12	2.99
halfbanded rockfish	1.78	0.00	2.47
longfin sanddab	1.62	1.62	2.33
pink seaperch	1.67	0.50	2.10
slender sole	1.53	0.00	2.09
California tonguefish	0.46	1.50	1.74
roughback sculpin	0.21	1.21	1.61
shortspine combfish	1.04	0.00	1.55
bigmouth sole	0.60	1.57	1.52
bay goby	1.11	0.50	1.48
Cluster Groups G & B	Group G	Group B	
halfbanded rockfish	5.57	0.00	7.60
Pacific sanddab	11.67	6.71	7.09
Dover sole	4.78	0.71	5.79
shortspine combfish	3.19	0.00	4.66
longspine combfish	2.98	1.12	3.15
slender sole	2.10	0.00	3.05
yellowchin sculpin	0.51	2.12	2.78
California lizardfish	1.59	0.71	2.42
plainfin midshipman	1.60	0.00	2.34
longfin sanddab	0.13	1.62	2.24
pink seaperch	1.88	0.50	1.98

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group “X”	Group “Y”	
Cluster Groups G & B *continued*	Group G	Group B	
greenstriped rockfish	1.36	0.00	1.96
English sole	1.59	0.50	1.78
bigmouth sole	0.50	1.57	1.68
California tonguefish	0.87	1.50	1.64
roughback sculpin	0.34	1.21	1.51
Cluster Groups C & B	Group C	Group B	
yellowchin sculpin	0.00	2.12	4.80
California lizardfish	1.70	0.71	4.15
bigmouth sole	0.00	1.57	3.61
California tonguefish	0.00	1.50	3.40
plainfin midshipman	1.38	0.00	3.17
Dover sole	2.02	0.71	2.97
stripetail rockfish	1.29	0.00	2.94
longfin sanddab	0.47	1.62	2.91
longspine combfish	1.24	1.12	2.60
greenstriped rockfish	1.14	0.00	2.60
Pacific sanddab	7.20	6.71	2.39
roughback sculpin	0.33	1.21	2.06
slender sole	0.80	0.00	1.74
pink seaperch	0.58	0.50	1.73
gulf sanddab	0.67	0.00	1.61
spotfin sculpin	0.58	0.00	1.48
greenblotched rockfish	0.80	0.50	1.48
Cluster Groups F & B	Group F	Group B	
Pacific sanddab	9.59	6.71	5.70
plainfin midshipman	2.53	0.00	4.63
Dover sole	3.00	0.71	4.27
stripetail rockfish	1.80	0.00	3.18
yellowchin sculpin	1.47	2.12	2.38
longfin sanddab	2.31	1.62	2.17
longspine combfish	0.53	1.12	2.08
shortspine combfish	1.07	0.00	2.00
California tonguefish	1.47	1.50	1.89
bigmouth sole	0.66	1.57	1.88
roughback sculpin	0.26	1.21	1.87
halfbanded rockfish	0.94	0.00	1.67

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups A & B	Group A	Group B	
halfbanded rockfish	4.00	0.00	11.64
yellowchin sculpin	0.00	2.12	6.02
Pacific sanddab	4.80	6.71	5.41
bigmouth sole	0.00	1.57	4.54
California tonguefish	0.00	1.50	4.26
roughback sculpin	0.00	1.21	3.47
longspine combfish	0.00	1.12	3.02
spotfin sculpin	1.00	0.00	2.91
greenspotted rockfish	1.00	0.00	2.91
gulf sanddab	1.00	0.00	2.91
Dover sole	0.00	0.71	2.21
California lizardfish	0.00	0.71	1.91
longfin sanddab	1.00	1.62	1.67
greenblotched rockfish	0.00	0.50	1.56
lingcod	0.00	0.50	1.56
squarespot rockfish	0.00	0.50	1.56
Cluster Groups E & B	Group E	Group B	
halfbanded rockfish	7.75	0.00	11.67
squarespot rockfish	4.80	0.50	6.45
Pacific sanddab	10.49	6.71	5.74
vermilion rockfish	2.45	0.00	3.69
greenblotched rockfish	2.83	0.50	3.48
stripetail rockfish	2.24	0.00	3.37
yellowchin sculpin	0.00	2.12	3.16
plainfin midshipman	2.00	0.00	3.01
shortspine combfish	1.73	0.00	2.61
longfin sanddab	0.00	1.62	2.40
roughback sculpin	0.00	1.21	1.81
longspine combfish	1.41	1.12	1.70
flag rockfish	1.00	0.00	1.51
bigmouth sole	1.00	0.00	1.51
California scorpionfish	1.00	0.00	1.51
greenspotted rockfish	1.00	0.00	1.51
rex sole	1.00	0.00	1.51
Cluster Groups D & B	Group D	Group B	
plainfin midshipman	10.77	0.00	16.33
Dover sole	6.00	0.71	7.98
gulf sanddab	2.24	0.00	3.39

Appendix E.4 *continued*

	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups D & B *continued*	Group D	Group B	
yellowchin sculpin	0.00	2.12	3.18
bigfin eelpout	2.00	0.00	3.03
Pacific sanddab	8.66	6.71	3.00
longfin sanddab	0.00	1.62	2.42
longspine combfish	2.65	1.12	2.38
bigmouth sole	0.00	1.57	2.38
California tonguefish	0.00	1.50	2.25
pink seaperch	2.00	0.50	2.25
slender sole	1.41	0.00	2.14
California scorpionfish	1.41	0.00	2.14
English sole	1.73	0.50	1.90
bigmouth sole	1.00	0.00	1.52
stripetail rockfish	1.00	0.00	1.52
California skate	1.00	0.00	1.52
spotted rockfish	1.00	0.00	1.52

Appendix E.5

List of megabenthic invertebrate taxa captured during 2009 at PLOO trawl stations. Data are number of individuals (*n*). Taxonomic arrangement from SCAMIT 2008.

Taxon/Species					*n*
SILICEA					
	DEMOSPONGIAE				
		Hadromerida			
			Suberitidae		
				Suberites sp	1
CNIDARIA					
	ANTHOZOA				
		Stolonifera			
			Telestidae		
				Telesto californica	1
		Alcyonacea			
			Plexauridae		
				Thesea sp B	1
		Pennatulacea			
			Virgulariidae		
				Acanthoptilum sp	355
		Actiniaria			
			Metridiidae		
				Metridium farcimen	2
MOLLUSCA					
	GASTROPODA				
		Hypsogastropoda			
			Turridae		
				Megasurcula carpenteriana	2
			Muricidae		
				Pteropurpura sp	1
		Opisthobranchia			
			Philinidae		
				Philine alba	5
			Arminidae		
				Armina californica	1
	CEPHALOPODA				
		Sepiolida			
			Sepiolidae		
				Rossia pacifica	3
		Octopoda			
			Octopodidae		
				Octopus rubescens	1
ANNELIDA					
	POLYCHAETA				
		Aciculata			
			Polynoidae		
				Hololepida magna	1
ARTHROPODA					
	MALACOSTRACA				
		Isopoda			
			Cymothoidae		
				Elthusa vulgaris	3
		Decapoda			
			Sicyoniidae		
				Sicyonia ingentis	13
			Diogenidae		
				Paguristes turgidus	1
			Inachoididae		
				Pyromaia tuberculata	1

Appendix E.5 *continued*

Taxon/Species	*n*
ECHINODERMATA	
ASTEROIDEA	
Paxillosida	
Luidiidae	
Luidia asthenosoma	1
Luidia foliolata	23
Astropectinidae	
Astropecten verrilli	6
OPHIUROIDEA	
Ophiurida	
Amphiuridae	
Amphichondrius granulatus	1
Ophiuridae	
Ophiura luetkenii	61
ECHINOIDEA	
Temnopleuroida	
Toxopneustidae	
Lytechinus pictus	9830
Echinoida	
Strongylocentrotidae	
Strongylocentrotus fragilis	367
Spatangoida	
Spatangidae	
Spatangus californicus	1
HOLOTHUROIDEA	
Aspidochirotida	
Stichopodidae	
Parastichopus californicus	20

Appendix E.6

Summary of total abundance by species and station for megabenthic invertebrates at the PLOO trawl stations during 2009.

Name	**January 2009**		**Species Abundance by Survey**
	SD10	**SD12**	
Lytechinus pictus	2100	3752	5852
Acanthoptilum sp	6	75	81
Luidia foliolata	1	13	14
Ophiura luetkenii	1	2	3
Parastichopus californicus	1	2	3
Astropecten verrilli	1		1
Winter Total	2110	3844	5954

Appendix E.6 *continued*

Name	July 2009						Species Abundance
	SD7	SD8	SD10	SD12	SD13	SD14	by Survey
Lytechinus pictus	736	1368	1516	34	153	171	3978
Strongylocentrotus fragilis					24	343	367
Acanthoptilum sp	2	1	2	200	38	31	274
Ophiura luetkenii		5	3	3	14	33	58
Parastichopus californicus	10	3		1	1	2	17
Sicyonia ingentis	2			9	2		13
Luidia foliolata		2	7				9
Astropecten verrilli			3	1		1	5
Philine alba	2	2				1	5
Elthusa vulgaris						3	3
Rossia pacifica				1		2	3
Megasurcula carpenteriana			1	1			2
Metridium farcimen			2				2
Amphichondrius granulatus					1		1
Armina californica					1		1
Hololepida magna		1					1
Luidia asthenosoma		1					1
Octopus rubescens				1			1
Paguristes turgidus		1					1
Pteropurpura sp	1						1
Pyromaia tuberculata	1						1
Spatangus californicus		1					1
Suberites sp		1					1
Telesto californica			1				1
Thesea sp B			1				1
Summer Total	754	1386	1536	251	234	587	4748

Appendix F

Supporting Data

2009 PLOO Stations

Bioaccumulation of Contaminants in Fish Tissues

Appendix F.1

Lengths and weights of fishes used for each composite (Comp) sample for the PLOO monitoring program during October 2009. Data are summarized as number of individuals (*n*), minimum (Min), maximum (Max), and mean values.

				Length (cm, size class)			Weight (g)		
Station	Comp	Species	n	Min	Max	Mean	Min	Max	Mean
RF1	1	Copper rockfish	3	26	39	34	515	1586	1181
RF1	2	Vermilion rockfish	3	20	36	26	188	1077	516
RF1	3	Mixed rockfish	3	29	31	30	768	797	779
RF2	1	Vermilion rockfish	3	31	34	33	823	1209	1004
RF2	2	Vermilion rockfish	3	33	41	37	977	1883	1412
RF2	3	Mixed rockfish	4	21	35	27	233	968	506
Zone 1	1	Pacific sanddab	4	17	20	19	71	132	101
Zone 1	2	Pacific sanddab	4	16	19	17	64	107	87
Zone 1	3	Pacific sanddab	3	18	22	20	96	176	133
Zone 2	1	Pacific sanddab	4	18	21	19	78	149	105
Zone 2	2	Pacific sanddab	3	17	22	20	67	154	115
Zone 2	3	Pacific sanddab	6	15	19	17	49	100	69
Zone 3	1	Pacific sanddab	3	17	21	19	74	158	105
Zone 3	2	Pacific sanddab	5	17	18	17	36	82	67
Zone 3	3	Pacific sanddab	3	19	22	21	96	184	137
Zone 4	1	Pacific sanddab	3	16	21	19	64	143	114
Zone 4	2	Pacific sanddab	4	15	22	17	60	180	94
Zone 4	3	Pacific sanddab	6	16	23	19	62	170	94

Appendix F.2

Constituents and method detection limits for fish tissue samples analyzed for the PLOO monitoring program during October 2009.

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
		Metals (ppm)			
Aluminum (Al)	3	3	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.2	0.2	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.24	0.24	Mercury (Hg)	0.03	0.03
Barium (Ba)	0.03	0.03	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.006	0.006	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Tl)	0.4	0.4
Copper (Cu)	0.1	0.1	Tin (Sn)	0.2	0.2
Iron (Fe)	2	2	Zinc (Zn)	0.15	0.15
		Chlorinated Pesticides (ppb)			
		HCH			
HCH, Alpha isomer	24.7	2.47	HCH, Delta isomer	4.53	0.45
HCH, Beta isomer	4.68	0.47	HCH, Gamma isomer	63.4	6.34
		Total Chlordane			
Alpha (cis) Chlordane	4.56	0.46	Heptachlor epoxide	3.89	0.39
Cis Nonachlor	4.7	0.47	Oxychlordane	7.77	0.78
Gamma (trans) Chlordane	2.59	0.26	Trans Nonachlor	2.58	0.26
Heptachlor	3.82	0.38			
		Total DDT			
o,p-DDD	2.02	0.2	p,p-DDE	2.08	0.21
o,p-DDE	2.79	0.28	p,-p-DDMU	3.29	0.33
o,p-DDT	1.62	0.16	p,p-DDT	2.69	0.27
p,p-DDD	3.36	0.34			
		Miscellaneous Pesticides			
Aldrin	88.1	8.81	Hexachlorobenzene (HCB)	1.63	0.13
Alpha Endosulfan	118	11.8	Mirex	1.49	0.15

Appendix F.2 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyl Congeners (PCBs) (ppb)					
PCB 18	2.86	0.29	PCB 126	1.52	0.15
PCB 28	2.47	0.28	PCB 128	1.23	0.12
PCB 37	2.77	0.25	PCB 138	1.73	0.17
PCB 44	3.65	0.36	PCB 149	2.34	0.23
PCB 49	5.02	0.50	PCB 151	1.86	0.19
PCB 52	5.32	0.53	PCB 153/168	2.54	0.25
PCB 66	2.81	0.28	PCB 156	0.64	0.06
PCB 70	2.49	0.25	PCB 157	2.88	0.29
PCB 74	3.10	0.31	PCB 158	2.72	0.27
PCB 77	2.01	0.20	PCB 167	1.63	0.16
PCB 81	3.56	0.36	PCB 169	2.76	0.28
PCB 87	3.01	0.30	PCB 170	1.23	0.12
PCB 99	3.05	0.30	PCB 177	1.91	0.19
PCB 101	4.34	0.43	PCB 180	2.58	0.26
PCB 105	2.29	0.23	PCB 183	1.55	0.15
PCB 110	2.50	0.25	PCB 187	2.50	0.25
PCB 114	3.15	0.31	PCB 189	1.78	0.18
PCB 118	2.06	0.21	PCB 194	1.14	0.11
PCB 119	2.39	0.24	PCB 201	2.88	0.29
PCB 123	2.64	0.26	PCB 206	1.28	0.13

Appendix F.3

Summary of constituents that make up total DDT and total PCB in each sample collected as part of the PLOO monitoring program during October 2009.

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	RF1	1	Copper rockfish	Muscle	PCB	PCB 99	0.4	ppb
2009-4	RF1	1	Copper rockfish	Muscle	PCB	PCB 101	0.5	ppb
2009-4	RF1	1	Copper rockfish	Muscle	PCB	PCB 110	0.5	ppb
2009-4	RF1	1	Copper rockfish	Muscle	PCB	PCB 138	0.6	ppb
2009-4	RF1	1	Copper rockfish	Muscle	PCB	PCB 153/168	1.1	ppb
2009-4	RF1	1	Copper rockfish	Muscle	PCB	PCB 180	0.5	ppb
2009-4	RF1	1	Copper rockfish	Muscle	PCB	PCB 187	0.5	ppb
2009-4	RF1	1	Copper rockfish	Muscle	DDT	p,-p-DDMU	0.2	ppb
2009-4	RF1	1	Copper rockfish	Muscle	DDT	p,p-DDE	8.8	ppb
2009-4	RF1	2	Vermilion rockfish	Muscle	PCB	PCB 101	0.4	ppb
2009-4	RF1	2	Vermilion rockfish	Muscle	PCB	PCB 153/168	0.6	ppb
2009-4	RF1	2	Vermilion rockfish	Muscle	DDT	p,-p-DDMU	0.3	ppb
2009-4	RF1	2	Vermilion rockfish	Muscle	DDT	p,p-DDE	4.3	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 49	0.2	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 52	0.7	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 66	0.1	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 70	0.3	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 74	0.2	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 87	0.8	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 99	1.3	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 101	1.6	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 105	0.6	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 110	1.7	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 118	2.0	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 128	0.4	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 138	1.6	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 149	0.4	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 153/168	1.8	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 180	0.7	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	PCB	PCB 187	0.4	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	DDT	p,-p-DDMU	0.2	ppb
2009-4	RF1	3	Mixed rockfish	Muscle	DDT	p,p-DDE	8.3	ppb
2009-4	RF2	1	Vermilion rockfish	Muscle	PCB	PCB 138	0.3	ppb
2009-4	RF2	1	Vermilion rockfish	Muscle	PCB	PCB 153/168	0.5	ppb
2009-4	RF2	1	Vermilion rockfish	Muscle	DDT	p,-p-DDMU	0.3	ppb
2009-4	RF2	1	Vermilion rockfish	Muscle	DDT	p,p-DDE	4.8	ppb
2009-4	RF2	2	Vermilion rockfish	Muscle	PCB	PCB 101	0.5	ppb
2009-4	RF2	2	Vermilion rockfish	Muscle	PCB	PCB 118	0.4	ppb
2009-4	RF2	2	Vermilion rockfish	Muscle	PCB	PCB 138	0.4	ppb
2009-4	RF2	2	Vermilion rockfish	Muscle	PCB	PCB 153/168	1.0	ppb
2009-4	RF2	2	Vermilion rockfish	Muscle	PCB	PCB 187	0.3	ppb
2009-4	RF2	2	Vermilion rockfish	Muscle	DDT	p,-p-DDMU	0.5	ppb
2009-4	RF2	2	Vermilion rockfish	Muscle	DDT	p,p-DDE	7.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	RF2	3	Mixed rockfish	Muscle	PCB	PCB 118	0.3	ppb
2009-4	RF2	3	Mixed rockfish	Muscle	PCB	PCB 153/168	0.5	ppb
2009-4	RF2	3	Mixed rockfish	Muscle	DDT	p,p-DDE	3.6	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 28	1.1	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 49	3.2	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 52	4.3	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 66	2.6	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 70	2.9	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 74	2.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 99	19.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 101	18.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 110	8.6	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 118	19.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 128	6.3	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 138	30.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 149	7.8	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 151	6.3	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 153/168	47.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 167	1.6	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 170	4.7	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 177	4.5	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 180	18.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 183	6.1	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 187	19.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 194	5.4	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 201	5.4	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	23.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDD	7.4	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDE	420.0	ppb
2009-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDT	8.9	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 49	2.7	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 52	4.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 66	2.7	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 70	2.7	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 74	2.4	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 99	15.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 101	12.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 110	7.6	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 118	17.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 128	6.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 138	29.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 149	7.6	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 151	5.9	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 153/168	46.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 170	7.3	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 180	17.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 187	17.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 194	3.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	20.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDD	6.6	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDE	300.0	ppb
2009-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDT	8.1	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 52	5.1	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 66	1.8	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 70	3.2	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 74	1.8	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 99	15.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 101	14.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 110	9.7	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 118	15.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 128	4.7	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 138	23.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 149	5.9	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 151	5.6	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 153/168	39.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 180	14.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 187	18.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 194	5.1	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	20.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDD	6.1	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDE	310.0	ppb
2009-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDT	7.6	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 49	2.6	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 52	3.9	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 66	1.7	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 70	2.7	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 74	1.8	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 99	9.4	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 101	11.0	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 110	6.3	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 128	3.0	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 138	16.0	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 149	5.5	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 151	3.7	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 153/168	25.0	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 180	8.8	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 187	11.0	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 194	3.1	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	19.0	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDD	7.8	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDE	250.0	ppb
2009-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDT	16.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 66	1.4	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 70	1.9	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 74	1.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 99	11.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 101	11.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 110	6.3	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 118	11.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 138	17.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 149	4.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 151	5.4	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 153/168	30.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 180	12.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 183	4.4	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 187	15.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	15.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDD	4.9	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDE	220.0	ppb
2009-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDT	4.9	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 52	5.5	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 66	3.6	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 70	2.6	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 74	2.6	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 99	21.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 101	23.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 105	6.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 110	7.8	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 118	23.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 128	7.1	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 138	40.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 149	16.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 151	8.3	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 153/168	65.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 170	8.9	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 180	29.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 183	6.9	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 187	27.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 194	5.2	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	DDT	o,p-DDE	11.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	23.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDD	11.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDE	940.0	ppb
2009-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDT	9.3	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 49	5.2	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 52	6.5	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 66	3.3	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 70	4.1	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 74	1.9	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 99	14.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 101	19.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 110	13.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 118	19.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 128	4.4	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 138	20.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 149	8.2	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 151	4.7	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 153/168	32.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 180	14.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 187	13.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	23.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDD	6.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDE	370.0	ppb
2009-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDT	9.9	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 52	5.1	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 66	3.5	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 70	2.1	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 74	2.1	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 99	17.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 101	19.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 110	13.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 118	21.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 128	6.4	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 138	35.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 149	9.7	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 151	7.7	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 153/168	47.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 156	3.5	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 180	17.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 183	6.3	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 187	23.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 194	4.7	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	25.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDD	5.1	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDE	340.0	ppb
2009-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDT	12.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 49	5.7	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 52	7.8	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 66	3.7	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 70	5.3	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 74	2.1	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 99	19.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 101	21.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 105	5.8	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 110	17.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 118	24.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 138	31.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 149	13.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 151	9.8	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 153/168	53.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 180	19.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 183	4.9	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 187	23.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 194	4.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	11.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,p-DDD	5.1	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,p-DDE	240.0	ppb
2009-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,p-DDT	8.5	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 52	4.9	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 66	2.7	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 70	2.9	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 74	2.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 99	15.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 101	14.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 105	4.3	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 110	11.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 118	15.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 128	5.9	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 138	25.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 149	7.3	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 151	6.1	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 153/168	39.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 170	8.2	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 180	15.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 187	16.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 194	3.6	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	18.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDD	5.1	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDE	330.0	ppb
2009-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDT	8.3	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 49	3.4	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 52	4.8	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 70	3.9	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 99	13.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 101	20.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 105	4.9	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 110	12.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 118	18.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 128	4.6	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 138	26.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 149	11.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 151	7.4	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 153/168	46.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 170	5.3	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 180	17.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 183	6.4	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 187	19.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 194	4.3	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	18.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDD	5.6	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDE	350.0	ppb
2009-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDT	8.2	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 49	2.9	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 52	4.4	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 66	2.1	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 70	2.6	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 74	1.6	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 99	15.5	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 101	11.0	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 105	4.9	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 110	8.5	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 118	18.0	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 128	4.4	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 138	27.5	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 149	5.8	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 151	5.3	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 153/168	40.5	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 170	6.8	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 180	16.0	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 183	6.5	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 187	17.5	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 194	5.0	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	19.5	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDD	5.8	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDE	365.0	ppb
2009-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDT	8.3	ppb